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(54) ERK INHIBITORS FOR USE IN TREATING SPINAL MUSCULAR ATROPHY

ERK-INHIBITOREN ZUR VERWENDUNG BEI DER BEHANDLUNG VON SPINALER MUSKELATROPHIE

INHIBITEURS DE LA VOIE ERK POUR LE TRAITEMENT DE L'AMYOTROPHIE SPINALE

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(56) References cited:
WO-A1-2009/036020 **WO-A1-2010/148249**
WO-A2-02/094842 **US-A1- 2007 292 408**

- **PASSINI MARCO A ET AL: "Antisense oligonucleotides delivered to the mouse CNS ameliorate symptoms of severe spinal muscular atrophy.", SCIENCE TRANSLATIONAL MEDICINE 2 MAR 2011 LNKD-PUBMED:21368223, vol. 3, no. 72, 2 March 2011 (2011-03-02), page 72RA18, XP9161512, ISSN: 1946-6242**
- **MILLINO CATERINA ET AL: "Different atrophy-hypertrophy transcription pathways in muscles affected by severe and mild spinal muscular atrophy", BMC MEDICINE, BIOMED CENTRAL LTD., LONDON, GB, vol. 7, no. 1, 7 April 2009 (2009-04-07), pages 14-22, XP021051386, ISSN: 1741-7015, DOI: 10.1186/1741-7015-7-14**

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to of an ERK inhibitor, such as Selumetinib, for use in treating spinal muscular atrophy in a subject in need thereof.

BACKGROUND OF THE INVENTION

[0002] Spinal Muscular Atrophy (SMA) is a recessive neurodegenerative disease characterized by the selective loss of spinal motor neurons[1]. SMA is caused by mutation of the Survival-of-Motor-Neuron 1 (*SMN1*) gene[2] and deficiency of the survival motor neuron (SMN) protein expression. All patients retain one or more copies of the *SMN2* gene, which modulates the disease severity by producing a small amount of full-length SMN transcripts and consequently of stable SMN protein[3]. Since SMA is caused by insufficient amounts of SMN protein, a major aim of SMA therapeutics strategy is to increase SMN protein levels by activating *SMN2* gene expression. However, todate there is no available therapy for SMA, which represents the leading genetic cause of death in childhood.

[0003] The mode of action of therapeutic molecules for the treatment of SMA may include the increase of SMN expression particularly in motor neurons through activating the *SMN2* promoter, increasing exon-7 inclusion in SMN transcripts, or extending the half-life of SMN mRNA or protein.

[0004] It may also include the promotion of motor neuron survival through the activation of anti-apoptotic pathways. Over the years, a number of groups have identified *SMN2* gene-inducing compounds using cultured fibroblasts derived from SMA patients, and which benefits were often further tested in vivo in SMA mouse models[5]. Among those, SMN inducer compounds were identified based on their supposed ability to increase general gene expression, such as histone deacetylase inhibitors[6, 7, 8,] or by high throughput screenings, such as quinazoline derivatives[9, 10]. Unfortunately, to date, many of these compounds were disappointing in clinical trials with no substantial clinical benefit demonstrated[11, 12, 13]. Ultimately, none of these compounds provide efficient anti-apoptotic potential for motor neurons.

[0005] One promising, as yet unexplored, therapeutic development for SMA could involve the pharmacological correction of molecular mechanisms, specifically altered in SMA neuromuscular system, potentially capable of modulating either SMN expression, or motor-neuron survival or both.

[0006] However, there is still a need to understand the molecular pathways involved in the modulation of SMN expression or motor-neuron survival and identify efficient strategies for treating SMA.

[0007] Constitutively down-regulated in mouse SMA spinal cord, the AKT/CREB pathway is able to remarkably alleviate SMA symptoms in mice as long as it is reactivated[14]. In very severe SMA-like mice[15], the reactivation of AKT/CREB pathway by NMDA resulted in an increased in the total amount of SMN transcripts in the SMA spinal cord without modifying its splicing pattern suggesting a SMN2 gene regulation at the transcriptional level[14]. Furthermore, considered as a common and powerful antiapoptotic pathway[16] notably for spinal motor neurons[17], the AKT/CREB pathway activation likely represents an important clue for motor neuron resistance to cell death in SMA spinal cord. Thus, identifying therapeutic agents that could lead to the reactivation of the AKT/CREB pathway in SMA spinal cord has been suggested as a possible approach for treating SMA.

[0008] International Patent Publication No. WO2010/148249 (Isis Pharmaceuticals, Genzyme Corp, Cold Spring Harbor Laboratory) describes methods and compositions for modulating splicing of SMN2 mRNA in a subject, for the treatment of spinal muscular atrophy.

[0009] Interestingly, the activation profile of another major intracellular signaling pathway in neurons[18], namely the ERK1/2 signaling pathway, was in opposite contrast to that of AKT in SMA spinal cord. Constitutively over-activated in the spinal cord of two different severe mouse models of SMA, characterized by a weak SMN expression, ERK1/2 was inhibited when AKT is reactivated and this change in ERK/AKT activation balance correlated with an increase in SMN expression[14]. However, these data failed to show any direct link between a modulation of ERK 1/2 signaling pathway and SMN2 gene regulation.

[0010] ERK inhibitors, such as Selumetinib have been described in the Art for their use in treating cancer disorders (see for example, Adjei et al. J Clin Oncol 2008 26(13):2139-2146; Board et al. Br J Cancer 2009 101(10):1724-30; Kolb et al. Pediatr Blood Cancer 2010 55(4):668-677). To Applicant's knowledge, these molecules have never been described for their use in treating spinal muscular atrophy or related disorders.

[0011] Thus, it is of the merit of the inventors to have provided new data showing that the pharmacological inhibition of ERK pathway, notably through the use of Selumetinib or related ERK inhibitors, could be an efficient treatment to alleviate SMA symptoms or related disorders associated to SMN deficiency resulting in loss of motor function in patients.

SUMMARY

[0012] Therefore, it is an object of the present disclosure to provide methods for treating a neuromuscular disorder associated to a SMN deficiency resulting in loss of motor function, said method comprising administering a therapeutically efficient amount of an ERK inhibitor in a subject in need thereof.

[0013] A neuromuscular disorder that can be treated with the method of the disclosure is spinal muscular atrophy resulting from a genetic mutation in SMN1 gene.

[0014] The invention relates to Erk inhibitors for use in treating spinal muscular atrophy, according to the claims.

[0015] ERK inhibitors for use according to the invention may be selected from MEK1/2 inhibitors, preferably from known MEK1/2 inhibitors with an IC50 of at least 1μM, or less.

[0016] Typical examples of such known MEK1/2 inhibitors include, without limitation, selumetinib (also known as AZD6244), U0126, PD98059, PD0325901, AZD8330(ARRY-42704), CI-1040 (PD184352), PD318088.

[0017] In a preferred embodiment, said ERK inhibitors for use according to the invention are selected from Selumetinib or its derivatives or pharmaceutically acceptable salts.

[0018] In another embodiment, ERK inhibitors for use according to the invention are selected from the group consisting of nucleic acid molecules such siRNA, shRNA, and anti-sense oligonucleotides, said nucleic acid molecules being capable of reducing the expression of MEK1, MEK2, ERK1 and/or ERK2.

[0019] Preferably, said ERK inhibitors for use according to the invention, are administered orally to a subject in an amount effective to treat spinal muscular atrophy.

[0020] The disclosure further relates to a pharmaceutical composition comprising an ERK inhibitor in combination with another active principle ingredient for the treatment of spinal muscular atrophy and a pharmaceutically acceptable. The other active principle ingredient is selected from the group consisting siRNA, shRNA or antisense compounds directed against nucleic acid encoding a deficient SMN1 gene product resulting in loss of motor function.

DETAILED DESCRIPTION

ERK inhibitors for use in the treatment of spinal muscular atrophies or related neuromuscular disorders

[0021] The disclosure more specifically relates to ERK inhibitors for use as a drug in the treatment of a neuromuscular disorder associated to a SMN deficiency resulting in loss of motor function. As used herein, the term "treatment" refers to any methods appropriate to cure, ameliorate, stabilize and/or prevent a disease or one or more of the symptoms of such disease.

[0022] The term "ERK inhibitors" as used herein relates to compounds capable of fully or partially preventing, or reducing or inhibiting MEK ERK1/2 signaling activity.

[0023] Inhibition may be effective at the transcriptional level, for example by preventing or reducing or inhibiting mRNA synthesis of key members of MEK ERK1/2 signaling pathway, such as MEK1, MEK2, ERK1 or ERK2 mRNA, for example, mRNA encoding human MEK1 (NCBI reference NP-002746), human MEK2 (NCBI reference NP109587), human ERK1 (NCBI reference NP-002737) or human ERK2 (NCBI reference NP-620407).

[0024] As used herein the term "signalling pathway" or "signalling activity" refers to a biochemical causal relationship generally initiated by a protein-protein interaction such as binding of a growth factor to a receptor, resulting in transmission of a signal from one portion of a cell to another portion of a cell. In general, the transmission involves specific phosphorylation of one or more tyrosine, serine, or threonine residues on one or more proteins in the series of reactions causing signal transduction. Penultimate processes typically include nuclear events, resulting in a change in gene expression.

[0025] The MEK ERK1/2 signalling pathway refers to the signalling pathway involving MEK and ERK (standing for Extracellular signals Regulated Kinase) serine/threonine selective protein kinases. Specific receptor kinases are activated through diverse extracellular stimuli and thus recruit the Ras family small G proteins, which lead to the sequential activation of Raf (MAPK kinase kinase), MEK (MAPK kinase) and ERK (MAPK). MAPK/ERK activity requires phosphorylation on both threonine (T185) and tyrosine (Y187).

[0026] The term "ERK inhibitor" is intended to refer to a substance that reduces, decreases and/or inhibits MEK ERK1/2 signaling activity as measured by the relative amount of phosphorylated ERK proteins or phosphorylated Elk1 protein. Methods for detecting and measuring relative amount of phosphorylated ERK proteins or phosphorylated Elkl protein are described in the Examples.

[0027] In a specific embodiment, said ERK inhibitors are compound inhibitor inhibiting MEK1, MEK2, ERK1 or ERK2 kinase activity. Specific inhibition may be measured as IC50 in a functional assay for MEK ERK1/2 signaling activity and the selected inhibitors may have an IC50 of 100μM or less, 10μM or less, 1μM or less, 100nM or less, 10nM or less or 1nM or less. Assays for measuring MEK1/2 kinase activity are commercially available.

[0028] Such inhibitors may thus be selected among small molecule, siRNA, shRNA, anti-sense DNA and the like.

[0029] In one embodiment, an ERK inhibitor for use according to the present invention is a small molecule. In another

embodiment, said ERK inhibitor is selected from the group consisting of siRNA, shRNA, anti-sense oligonucleotides and related nucleic acids capable of inhibiting MEK1, MEK2, ERK1 and/or ERK2 gene expression.

Small molecule ERK inhibitors

[0030] In one embodiment, an ERK inhibitor for use in the treatment of spinal muscular atrophy or related disorders is a small molecule ERK inhibitor.

[0031] As used herein, the term "small molecule" refers to a low molecular weight organic compound which is not a polymer. Preferably, it has a molecular weight not upper than 800 Daltons so that it can rapidly diffuse across cell membranes so that they can reach intracellular sites of action.

[0032] A variety of a small molecule ERK inhibitors have been described in the Art, in particular MEK inhibitors such as MEK1 and/or MEK2 inhibitors, also referred as MEK1/2 inhibitors.

[0033] Such inhibitors include, but are not limited to, chromone and flavone type inhibitors. Other examples of suitable small molecule ERK inhibitors include, but are not limited to, PD 98059, a highly selective inhibitor of MEK1 and MEK2 with IC50 values of 4 μM and 50 μM respectively (Runden E et al., J Neurosci 1998, 18(18) 7296-305), PD0325901 (Pfizer), Selumetinib, a selective MEK inhibitor (AstraZeneca/Array BioPharma, also known as AZD6244), ARRY-438162 (Array BioPharma), PD198306 (Pfizer), PD0325901 (Pfizer), AZD8330 (AstraZeneca/Array Biopharma, also called ARRY-424704), PD184352 (Pfizer, also called CI- 1040), PD 184161 (Pfizer), α-[Amino[(4-aminophenyl)thio]methylene]-2-(trifluoromethyl)benzeneacetonitrile (SL327), 1,4-Diamino-2,3-dicyano-1,4-bis(2-aminophenylthio)butadiene (DeSilva, D.R., et al. 1998. J. Immunol. 160, 4175. 165. Duncia, J.V., et al. 1998. Biorg. Med. Chem. Lett. 8, 2839. 166. Favata, M.F., et al. 1998. J. Biol. Chem. 273, 18623. 167. Ahn et al. (1999) Promega Notes. 71 : 4.), U0126 (Kohno & Pouyssegur (2003) Prog. Cell. Cyc. Res. 5: 219-224), GW 5074 (Santa Cruz Biotechnology), BAY 43-9006 (Bayer, Sorafenib), Ro 09-2210 (Roche, Williams et al., Biochemistry. 1998 Jun 30;37(26):9579-85), FR 1 80204 (Ohori, M. et al. (2005) Biochem. Biophys. Res. Comm. 336: 357-363.), 3- (2-aminoethyl)-5-))4-ethoxyphenyl)methylene)-2,4-thiazolidinedione (PKI-ERK-005) (Chen, F. et al. (2006) Bioorg. Med. Chem. 16:6281- 6288. 171. Hancock, CN. et al. (2005) J. Med. Chem. 48: 4586-4595), CAY10561 (CAS 933786-58-4; Cayman Chemical), GSK 120212, RDEA1 19 (Ardea Biosciences), XL518, and ARRY-704 (AstraZeneca).

[0034] Other ERK inhibitors and their synthesis methods have been described in US 5,525,625, WO 98/43960, WO 99/01426, WO 00/41505, WO 00/42002, WO 00/42003, WO 00/41994, WO 00/42022; WO 00/42029, WO 00/68201; WO 01/68619; WO 02/06213: WO 03/077855 and WO 2005/23251.

[0035] Such ERK inhibitors further include, without limitation, a peptide inhibitor corresponding to the amino-terminal 13 amino acids of MEK1 (MPKKKPTPIQLNP) (Kohno & Pouyssegur (2003) Prog. Cell. Cyc. Res. 5: 219-224). Peptide inhibitors may be obtained using usual chemical peptide synthesis or genetic engineering methods. Such peptide inhibitor may further be fused to additional peptide sequences, e.g. to linker, signal or leader sequences. A tag refers to a distinct amino acid sequence that can be used to detect or purify the peptide sequence but does not contribute to the essential function of ERK inhibition. Such peptide inhibitors may further be linked to internalization peptides or protein transduction domain such as the TAT transactivation domain of HIV, antennapedia, and transportan that can readily target molecules and small peptides across the plasma membrane into the cell (Schwarze et al., Science. 1999 285(5433): 1569-72).

[0036] A series of 3-cyano-4-(phenoxyanilo-)quinolines with MEK inhibitory activity has also been developed by Wyeth-Ayerst (Zhang N. et al., Bioorg Med. Chem. Lett., 2000, 10: 2825-2828).

[0037] Several resorcyclic acid lactones having inhibitor activity toward MEK have been isolated from microbial extracts. For example, Ro 09-2210, isolated from fungal broth FC2506, and L-783,277, purified from organic extracts of Phoma sp. are competitive with ATP, and the MEK1 inhibition is reversible (Williams D.H. et al., Biochemistry, 1998, 37: 9579-9585; and Zhao A. et al., J. Antibiot., 1999, 52: 1086-1094).

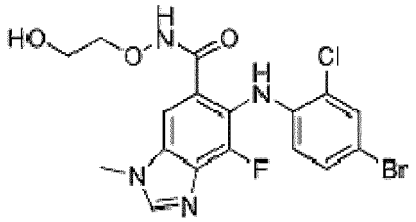
[0038] Purvalanol, a cyclin-dependent kinase (CDK) inhibitor has also been shown to target ERK1 and ERK2 (Knockhaert M. et al., Oncogene, 2002, 21: 6413-6424).

[0039] Other ERK inhibitors that may be used in accordance with the present invention include those disclosed in U.S. patent publication 2003/0060469, U.S. patent publication 2004/0048861 and US patent publication 2004/0082631.

[0040] In a preferred embodiment, said ERK inhibitor is an inhibitor of MEK1 and/or MEK2 kinases selected from the group consisting of selumetinib, U0126, PD98059, PD0325901, AZD8330(ARRY-42704), CI-1040 (PD184352), PD318088.

[0041] Preferably, said ERK inhibitor is selected from the group consisting of semuletinib and its derivatives and pharmaceutically acceptable salts thereof.

[0042] Selumetinib, also known as AZD6244 is a MEK1/2 inhibitor having the following formula (I):



(I)

6-(4-bromo-2-chloroanilino)-7-fluoro-N-(2-hydroxyethoxy)-3-methylbenzimidazole-5-carboxamide

[0043] Methods for synthesizing Selumetinib and other derivatives of Selumetinib or its pharmaceutically acceptable salts that can be used as ERK inhibitors according to the present invention have also been described in EP2275102 (see in particular Formula I as disclosed in EP2275102), WO 03/077855, and WO 03/077914.

siRNAs

[0044] Small inhibitory RNAs (siRNAs) can function as inhibitors of gene expression of a component of MEK/ERK1/2 signaling, thereby acting as ERK inhibitors. For example, gene expression of MEK1, MEK2, ERK1 or ERK2 can be reduced by contacting a subject or cell with a small double stranded RNA (dsRNA), or a vector or construct causing the production of a small double stranded RNA, such that said gene expression is specifically inhibited (i.e. RNA interference or RNAi). Methods for selecting an appropriate dsRNA or dsRNA-encoding vector are well known in the art for genes whose sequence is known (e.g. see for example Tuschl, T. et al. Genes Dev. 1999 Dec 15;13(24):3191-7; Elbashir, S. M. et al Nature. 2001 May 24;411(6836):494-8; Hannon, GJ. Nature. 2002 Jul 11;418(6894):244-51); McManus, MT. et al. J Immunol 169, 5754-5760 (2002).; Brummelkamp, TR. et al. Science. 2002 Apr 19; 296(5567):550-3 ; U.S. Pat. Nos. 6,573,099 and 6,506,559; and International Patent Publication Nos. WO 01/36646, WO 99/32619, and WO 01/68836). All means and methods which result in a decrease in MEK1, MEK2, ERK1 or ERK2 expression, in particular by taking advantage of MEK1, MEK2, ERK1 or ERK2-specific siRNAs (i.e siRNAs that target specifically MEK1, MEK2, ERK1 or ERK2 mRNA) may be used in the present invention. Methods for generating and preparing siRNA(s) as well as method for inhibiting the expression of a target gene are also described for example in WO02/055693.

[0045] siRNAs or related nucleic acids useful as inhibitors of MEK1, MEK2, ERK1 or ERK2 gene expression, such as anti-sense oligonucleotides can be prepared by known methods. These include techniques for chemical synthesis such as, e.g., by solid phase phosphoramadite chemical synthesis. Alternatively, anti-sense RNA molecules can be generated by in vitro or in vivo transcription of DNA sequences encoding the RNA molecule. Such DNA sequences can be incorporated into a wide variety of vectors that incorporate suitable RNA polymerase promoters such as the T7 or SP6 polymerase promoters. Various modifications to the oligonucleotides can be introduced as a means of increasing intracellular stability and half-life. Possible modifications include but are not limited to the addition of flanking sequences of ribonucleotides or deoxyribonucleotides to the 5' and/or 3' ends of the molecule, or the use of phosphorothioate or 2'-O-methyl rather than phosphodiesterase linkages within the oligonucleotide backbone. Those modification includes the use of nucleosides with modified sugar moieties, including without limitation, 5'-vinyl, 5'-methyl (R or S), 4'-S, 2'-F, 2'-OCH_3 and 2'-$O(CH_2)_2OCH_3$ substituent groups. The substituent at the 2' position can also be selected from allyl, amino, azido, thio, O-allyl, O-C_1-C_{10} alkyl, OCF_3, $O(CH_2)_2SCH_3$, $O(CH_2)_2$-O-N(R_m)(R_n), and O-CH_2-C(=O)-N(R_m)(R_n), where each R_m and R_n is, independently, H or substituted or unsubstituted C_1-C_{10} alkyl.

[0046] Antisense oligonucleotides and siRNAs or related nucleic acids useful as inhibitors of MEK1, MEK2, ERK1 or ERK2 may be delivered in vivo alone or in association with a vector. In its broadest sense, a "vector" is any vehicle capable of facilitating the transfer of the antisense oligonucleotide or siRNA or related nucleic acids to the target cells, preferably those with deficient expression of SMN gene, such as muscular cells. Preferably, the vector transports the nucleic acid to cells with reduced degradation relative to the extent of degradation that would result in the absence of the vector. In general, the vectors useful in the invention include, but are not limited to, plasmids, phagemids, viruses, transposon-based vectors or other vehicles derived from viral or bacterial sources that have been manipulated by the insertion or incorporation of the antisense oligonucleotide or siRNA or related nucleic acid sequences. Viral vectors are a preferred type of vector and include, but are not limited to, nucleic acid sequences from the following viruses: retrovirus, such as moloney murine leukemia virus, harvey murine sarcoma virus, murine mammary tumor virus, and rouse sarcoma virus; adenovirus, adeno-associated virus; SV40-type viruses; polyoma viruses; Epstein-Barr viruses; papilloma viruses; herpes virus; vaccinia virus; polio virus; and RNA virus such as a retrovirus. One can readily employ other vectors not

named but known to the art.

[0047] Preferred viral vectors are based on non-cytopathic eukaryotic viruses in which non-essential genes have been replaced with the gene of interest. Non-cytopathic viruses include retroviruses (e.g., lentivirus), the life cycle of which involves reverse transcription of genomic viral RNA into DNA with subsequent proviral integration into host cellular DNA. Retroviruses have been approved for human gene therapy trials. Most useful are those retroviruses that are replication-deficient (i.e., capable of directing synthesis of the desired proteins, but incapable of manufacturing an infectious particle). Such genetically altered retroviral expression vectors have general utility for the high-efficiency transduction of genes in vivo. Standard protocols for producing replication-deficient retroviruses (including the steps of incorporation of exogenous genetic material into a plasmid, transfection of a packaging cell lined with plasmid, production of recombinant retroviruses by the packaging cell line, collection of viral particles from tissue culture media, and infection of the target cells with viral particles) are provided in Varmus, Harold; Coffin, John M.; Hughes, Stephen H., ed (1997). "Principles of Retroviral Vector Design". Retroviruses. Plainview, N.Y: Cold Spring Harbor Laboratory Press. ISBN 0-87969-571-4.

[0048] Preferred viruses for certain applications are the adeno-viruses and adeno-associated viruses or retroviral vectors such as lentiviruses, which are double-stranded DNA viruses that have already been approved for human use in gene therapy. Examples of such viral vectors includes vectors originated from retroviruses such as HIV (Human Immunodeficiency Virus), MLV (Murine Leukemia Virus), ASLV (Avian Sarcoma/Leukosis Virus), SNV (Spleen Necrosis Virus), RSV (Rous Sarcoma Virus), MMTV (Mouse Mammary Tumor Virus), etc, lentivirus, Adeno-associated viruses, and Herpes Simplex Virus, but are not limited to.

[0049] Theses viral vectors can be engineered to be replication deficient and is capable of infecting a wide range of cell types and species. It further has advantages such as, heat and lipid solvent stability; high transduction frequencies in cells of diverse lineages, including hemopoietic cells; and lack of superinfection inhibition thus allowing multiple series of transductions.

[0050] Other vectors include plasmid vector, cosmid vector, bacterial artificial chromosome (BAC) vector, transposon-based vector. Plasmids may be delivered by a variety of parenteral, mucosal and topical routes. For example, the DNA plasmid can be injected by intramuscular, eye, intradermal, subcutaneous, or other routes. It may also be administered by intranasal sprays or drops, rectal suppository and orally. It may also be administered into the epidermis or a mucosal surface using a gene-gun. The plasmids may be given in an aqueous solution, dried onto gold particles or in association with another DNA delivery system including but not limited to liposomes, dendrimers, cochleate and microencapsulation.

[0051] In a preferred embodiment, the antisense oligonucleotide, siRNA, shRNA or related nucleic acid sequence is under the control of a heterologous regulatory region, e.g., a heterologous promoter. The promoter can also be, e.g., a viral promoter, such as CMV promoter or any synthetic promoters.

[0052] siRNA can also be directly conjugated with a molecular entity designed to help targeted delivery. Examples of conjugates are lipophilic conjugates such as cholesterol, or aptamer-based conjugates. Cationic peptides and proteins are also used to form complexes with a negatively charged phosphate backbone of the siRNA.

Method of treatment and pharmaceutical compositions

[0053] Another object of the disclosure relates to a method for treating spinal muscular atrophy or related neuromuscular disorders associated to a SMN deficiency resulting in loss of motor function, comprising administering a therapeutically effective amount of compound which is an ERK inhibitor as described above, to a subject in need thereof.

[0054] In one aspect, the dislosure relates to a method for treating spinal muscular atrophy comprising administering to a subject in need thereof a therapeutically effective amount of ERK inhibitor, such as Selumetinib or its derivatives or pharmaceutically acceptable salts as described above.

[0055] In another aspect, the disclosure provides ERK inhibitors as described above, which may be used for the preparation of a pharmaceutical composition for the treatment of spinal muscular atrophy or related neuromuscular disorders associated to a SMN deficiency resulting in loss of motor function.

[0056] ERK inhibitors may be administered in the form of a pharmaceutical composition, as defined below.

[0057] By a "therapeutically effective amount" is meant a sufficient amount of ERK inhibitor to treat and/or to prevent, reduce and/or alleviate one or more of the symptoms of spinal muscular atrophy or related neuromuscular disorders.

[0058] In one aspect, said related neuromuscular disorder is selected from the group consisting of amyotrophic lateral sclerosis (also known as Charcot's disease or Lou Gehrig's disease or motoneuron's disease).

[0059] It will be understood that the total daily usage of the compounds and compositions for use according to the present invention will be decided by the attending physician within the scope of sound medical judgment. The specific therapeutically effective dose level for any particular patient will depend upon a variety of factors including the disorder being treated and the severity of the disorder; activity of the specific compound employed; the specific composition employed, the age, body weight, general health, sex and diet of the patient; the time of administration, route of administration, and rate of excretion of the specific compound employed; the duration of the treatment; drugs used in combination or coincidental with the specific polypeptide employed; and like factors well known in the medical arts. For example, it

is well known within the skill of the art to start doses of the compound at levels lower than those required to achieve the desired therapeutic effect and to gradually increase the dosage until the desired effect is achieved. However, the daily dosage of the products may be varied over a wide range from 0.01 to 1,000 mg per adult per day. Preferably, the compositions contain 0.01, 0.05, 0.1, 0.5, 1.0, 2.5, 5.0, 10.0, 15.0, 25.0, 50.0, 100, 250 and 500 mg of the active ingredient for the symptomatic adjustment of the dosage to the patient to be treated. A medicament typically contains from about 0.01 mg to about 500 mg of the active ingredient, preferably from 1 mg to about 100 mg of the active ingredient. An effective amount of the drug is ordinarily supplied at a dosage level from 0.0002 mg/kg to about 20 mg/kg of body weight per day, especially from about 0.001 mg/kg to 7 mg/kg of body weight per day.

[0060] Hence, the present invention also provides a pharmaceutical composition comprising an effective dose of ERK inhibitor, such as for example Selumetinib or its derivatives or pharmaceutically acceptable salts, for use according to the invention.

[0061] Any therapeutic agent for use according to the invention may be combined with pharmaceutically acceptable excipients, and optionally sustained-release matrices, such as biodegradable polymers, to form therapeutic compositions.

[0062] The therapeutic agent, i.e. the ERK inhibitors, may be combined with other active ingredients, for example siRNA, shRNA or antisense compounds directed against nucleic acid encoding a deficient SMN1 gene product resulting in loss of motor function.

[0063] In one specific aspect, such ERK inhibitors may be combined with compositions for modulating splicing of SMN2 mRNA, including without limitation, those disclosed in WO2010/148249.

[0064] In another specific aspect, the ERK inhibitors may be combined with c-Jun NH2-terminal kinase (JNK) inhibitor, such as those described in WO 2010/151638.

[0065] "Pharmaceutically" or "pharmaceutically acceptable" refers to molecular entities and compositions that do not produce an adverse, allergic or other reaction when administered to a mammal, especially a human, as appropriate. A pharmaceutically acceptable carrier or excipient refers to a non-toxic solid, semi-solid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type.

[0066] Pharmaceutically acceptable carriers include any and all solvents (such as phosphate buffered saline buffers, water, saline), dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents and the like. Formulations are described for example in Remington's Pharmaceutical Science (Martin E.W. (1995) Easton Pa., Mack Publishing Company, 19th ed.)

[0067] The form of the pharmaceutical compositions, the route of administration, the dosage and the regimen naturally depend upon the condition to be treated, the severity of the illness, the age, weight, and sex of the patient, etc.

[0068] The pharmaceutical compositions for use according to the invention can be formulated for a topical, oral, intranasal, parenteral, intraocular, intravenous, intramuscular or subcutaneous administration and the like.

Method of screening agents for treating spinal muscular atrophy or related disorders

[0069] A role for MEK ERK1/2 pathway in neuromuscular disorders associated to SMN deficiencies has neither been described nor proposed in the prior art. Therefore, it is most surprising that by inhibiting MEK ERK1/2 signaling pathway, SMN2 gene expression is significantly increased. Accordingly, the present disclosure provides method for screening agents for treating spinal muscular atrophy or related disorders, said method comprising screening ERK inhibitors.

[0070] In one specific embodiment, the disclosure provides methods for screening agents for treating spinal muscular atrophy or related disorders comprising (i) selecting compounds that binds to MEK1 or MEK2 kinases with high affinity in a primary binding assay and (ii) selecting from those binding compounds, the compounds that specifically inhibit MEK ERK1/2 signaling in a secondary functional assay.

[0071] The screening methods of the disclosure generally comprise a first primary binding screening assay, generally carried as a high throughput screening assay, designed to identify compounds that bind with a high affinity to MEK1 or MEK2 protein or ERK1 or ERK2 protein. In one embodiment, "high affinity" refers to compounds that binds to the target protein with a dissociation constant K_D of 100μM or less, 10μM or less, 1μM or less, 100nM or less, 10nM or less, or 1nM or less. K_D affinity can be measured for example using surface Plasmon resonance, such as Biacore® assay (Biacore Life Sciences).

[0072] Compounds may be tested from large libraries of small molecules, natural products, peptides, peptidomimetics, polypeptides, proteins or a combination thereof or any appropriate compound libraries for drug discovery. Synthetic compound libraries are commercially available from Maybridge Chemical Co (Trevillet, Cornwall, UK), Comgenex (Princeton, N.J.), Brandon Associates (Merrimack, N.H), and Microsource (New Milford, Conn.). Compounds may also be screened from derivatives of known ERK inhbitors.

[0073] Examples of such primary binding assays for identifying MEK1 or MEK2 binders include without limitations the FRET-assays or TR-FRETs (in "A homogeneous time resolved fluorescence method for drug discovery" in: High Throughput screening: the discovery of bioactive substances. Kolb (1997) J. Devlin. NY, Marcel Dekker 345-360).

[0074] Once hit molecules or binding compounds have been selected from the primary screening assay, they are

generally subject to a secondary functional assay for testing specific inhibition of MEK ERK1/2 signaling pathways. In one other aspect, such secondary functional assay is used as the primary assay for direct screening of compound inhibitors.

[0075] As used herein, the term "specific inhibition" refers to an inhibition that is dependent upon the presence of an activator of said MEK ERK1/2 signaling pathway, preferably dose-dependent. Intensity of the inhibition can be referred as IC_{50}, i.e, the concentration of the inhibitors required to obtain 50% of inhibition in a determined assay. In one aspect, specific inhibitors have an IC_{50} of 100μM or less, 10μM or less, 1μM or less, 100nM or less, 10nM or less or 1nM or less, as measured in the secondary functional assay.

[0076] The secondary screening may be for example a biochemical assay or cellular-based assay for detecting MEK ERK1/2 signaling inhibition.

[0077] Biochemical assay may for example include a substrate for MEK1 and MEK2 kinases (for example a recombinant ERK1 or ERK2 protein and purified MEK1 or MEK2 kinase or an enzyme with related activity) and means for detecting the phosphorylated substrate (P-ERK for example). Such means may be specific antibody for phosphorylated substrate. The assay consists in measuring the amount of phosphorylated substrate after incubation with the purified enzyme in the absence or presence of the tested compound. Inhibition is detected as a significant and dose-dependent decrease of phosphorylated substrate.

[0078] Cellular-based assay includes assays which enable the determination of the activation profile of known molecular targets of the MEK ERK1/2 pathway, including, without limitation, the transcription factor Elk1 as described in the Examples below.

[0079] Compounds that exhibit one or more inhibition properties, the "lead" molecules, may then be chemically modified, for example for improving their binding properties, their pharmacokinetic and pharmacodynamic properties (e.g. solubility and ADME properties).

[0080] Using the assays described in the present disclosure and the art related to known ERK inhibitors, the skilled person is thus able to identify novel ERK inhibitors, for use according to the present invention.

[0081] In the following, the invention will be illustrated by means of the following examples as well as the figures.

FIGURE LEGENDS

FIGURE 1:

[0082]

A. *Smn* Promoter site 1 sequence

B. *Smn* Promoter site 2 sequence

C and D. Western blot analysis and quantification of Elk-1 protein phosphorylation in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and NMDA-treated SMA-like mice at 6 days of age (n=2). Error bars indicate SEM. (*, $p<0.05$).

E and F. ChIP analysis of Phospho-Elk-1 in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and NMDA-treated SMA-like mice at 6 days of age (n=9). Quantitative real time PCR was performed to detect *SMN2* promoter site 1 (***E***) and site 2 (***F***). Error bars indicate SEM. (*, $p<0.05$; **, $p<0.01$; ***, $p<0.001$).

G and H. ChIP analysis of Phospho-CREB in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and NMDA-treated SMA-like mice at 6 days of age (n=9). Quantitative real time PCR was performed to detect *SMN2* promoter site 1 (***G***) and site 2 (***H***). Error bars indicate SEM. (**, $p<0.01$; ***, $p<0.001$).

I and J. ChIP analysis of Histone H3 acetylation in the ventral lumbar spinal cord of vehicle-and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and NMDA-treated SMA-like mice at 6 days of age (n=9). Quantitative real time PCR was performed to detect *SMN2* promoter site 1 (***I***) and site 2 (***J***). Error bars indicate SEM. (*, $p<0.05$; **, $p<0.01$; ***, $p<0.001$).

K and L. ChIP analysis of Histone H4 acetylation in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and NMDA-treated SMA-like mice at 6 days of age (n=9). Quantitative real time PCR was performed to detect *SMN2* promoter site 1 (***K***) and site 2 (***L***). Error

bars indicate SEM. (*, p<0.05; ***, p<0.001).

FIGURE 2:

[0083]

A and B. Western blot analysis and quantification of Elk-1 protein phosphorylation in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and U0126-treated SMA-like mice at 6 days of age (n=3). Error bars indicate SEM. (*, p<0.05).

C and D. Western blot analysis and quantification of SMN protein expression in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, vehicle SMA-like mice at 2 days of age and U0126-treated SMA-like mice at 6 days of age (n=2). Error bars indicate SEM. (*, p<0.05).

E. Quantitative analysis of the number of GEMS per motor neuron in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and U0126-treated SMA-like mice at 6 days of age (n=2).

F and G. Western blot analysis and quantification of AKT protein phosphorylation in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and U0126-treated SMA-like mice at 6 days of age (n=3). Error bars indicate SEM. (*, p<0.05).

H and I. Western blot analysis and quantification of CREB protein phosphorylation in the ventral lumbar spinal cord of vehicle- and NMDA-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and U0126-treated SMA-like mice at 6 days of age (n=3). Error bars indicate SEM. (*, p<0.05).

J and K. Western blot analysis and quantification of SMN protein expression in vehicle and U0126-treated human SMA cultured myotubes and myoblasts (n=2). Error bars indicate SEM. (*, p<0.05).

FIGURE 3:

[0084]

A and B. Western blot analysis and quantification of ERK protein phosphorylation in the control and SMA spinal cord explants in presence or not of NMDA and of the CREB inhibitor KG501 (n=2). Error bars indicate SEM. (*, p<0.05).

C and D. Western blot analysis and quantification of Elk-1 protein phosphorylation in the control and SMA spinal cord explants in presence or not of NMDA and of the CREB inhibitor KG501 (n=2). Error bars indicate SEM. (*, p<0.05).

E and F. Western blot analysis and quantification of AKT protein phosphorylation in the control and SMA spinal cord explants in presence or not of NMDA and of the CREB inhibitor KG501 (n=3). Error bars indicate SEM. (*, p<0.05).

G and H. Western blot analysis and quantification of SMN protein expression in the control and SMA spinal cord explants in presence or not of NMDA and of the CREB inhibitor KG501 (n=2). Error bars indicate SEM. (*, p<0.05).

FIGURE 4:

[0085]

A. Life span of U0126-treated (n=15) compared to vehicle-treated SMA-like mice (n=10).

B. Weight curve in U0126-treated (n=15) and vehicle-treated SMA-like mice (n=10) compared to U0126-treated (n=15) and vehicle-treated control (n=15).

C-F. Immunodetection of ChAT-positive motor-neurons in the lumbar spinal cord (L1-L5) of 6 days of age vehicle- (***C***) and U0126-treated control mice (***D***), and 2 days of age vehicle- (***E***) and 6 days of age U0126-treated SMA-like mice (***F***).

G and H. Quantitative analysis of the number (***G***) and the cell body area (***H***) of motor neurons per ventral horn in the ventral lumbar spinal cord of vehicle- and U0126-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and U0126-treated SMA-like mice at 6 days of age (n=3). Error bars indicate SEM. (*, $p<0.05$).

I and J. Western blot analysis and quantification of SMN protein expression in the ventral lumbar spinal cord of vehicle- and AZD6244-treated control mice at 6 days of age, vehicle SMA-like mice at 2 days of age and AZD6244-treated SMA-like mice at 6 days of age (n=3). Error bars indicate SEM. (*, $p<0.05$).

K and L. Western blot analysis and quantification of AKT protein phosphorylation in the ventral lumbar spinal cord of vehicle- and AZD6244-treated control mice at 6 days of age, of vehicle SMA-like mice at 2 days of age and AZD6244-treated SMA-like mice at 6 days of age (n=3). Error bars indicate SEM. (*, $p<0.05$).

M. Life span of AZD6244-treated (n=10) compared to vehicle-treated SMA-like mice (n=10).

N. Weight curve in AZD6244-treated (n=10) and vehicle-treated SMA-like mice (n=10) compared to AZD6244-treated (n=10) and vehicle-treated control (n=10).

EXAMPLES

Materials and Methods

Mice and treatments

[0086] The knockout-transgenic SMA-like mice ($Snm^{-/-}$, $SMN2^{+/+}$) were purchased from the Jackson Laboratory (Bar Harbor, ME) and genotyped as previously described[15]. Vehicle-treated group, NMDA-treated group, U0126-treated group and AZD6244-treated group of type 1 SMA-like mice were randomly constituted in a blind systematic manner to minimize bias. The control mice were heterozygous knock-out for Smn with the human SMN2 transgene ($Smn^{-/+}$, $SMN2^{+/+}$).

[0087] In order to evaluate phospho-Elk-1 and phospho-CREB role on Smn2 promoter, P1 neonatal control and SMA-like mice, were either injected intrathecally with 5 pmol of N-methyl-D-aspartic Acid 100 μM (NMDA, Sigma, Saint Quentin Fallavier, France) in 0.5 μl/g of 0.9% NaCl dyed in blue Evans per gram. These mice were compared to control and SMA-like mice injected from P1 with 0.5 μl/g of 0.9% NaCl dyed in blue Evans.

[0088] In order to evaluate the benefits of phospho-ERK inhibition, P1 neonatal control and type 1 SMA-like mice were injected either intrathecally with 0.5 pmol of 1,4-Diamino-2,3-dicyano-1,4-bis(o-aminophenylmercapto)butadiene monoethanolate 10 μM (U0126, Sigma, Saint Quentin Fallavier, France) in 0.5 μl/g of 0.9% NaCl 1% DMSO dyed in blue Evans per gram, or per os with 0.5 pmol of Selumetinib 10 μM (AZD6244, Selleck chemicals, Houston, TX) in 2 μl/g of 0.9% NaCl 1% DMSO. These mice were compared to control and SMA-like mice either injected from P1 with 0.5 μl/g of 0.9% NaCl 1% DMSO dyed in blue Evans or orally treated with 2 μl/g of 0.9% NaCl 1% DMSO. Body weight and life span recordings were performed every day until the death of the animal. The animals were considered as dead when mice were no longer able to stand up 20 sec after having been placed on their sides.

[0089] The care and treatment of animals followed the national authority (Ministère de la Recherche et de la Technologie, France) guidelines for the detention, use and the ethical treatment of laboratory animals.

Mouse cell cultures and treatments

[0090] Co-cultures of spinal cord explants (around 1 mm^3) and muscle cells were performed as described by Kobayashi et al.[25] with the following modifications. Spinal cord explants were obtained from control and severe SMA embryonic mice. Explants from the whole transverse slices of 10.5 days-old mice embryo spinal cords including dorsal root ganglia (DRG) were placed on the muscle monolayer. DRG are essential to ensure a good innervation ratio[25]. The muscle culture was established through the differentiation of the wild-type muscle cell line C2C12. Myoblast cells were cultured on 35 mm petri dish at 37°C in 5% CO_2 in Dulbecco's Modified Eagle's Medium (DMEM) supplemented with 2 mM glutamine, 20% fetal bovin serum, 2% penicillin/streptomycin (5000 U). All the culture medium reagents were purchased from Invitrogen Life Technologies (Cergy-Pontoise, France). Confluent myoblasts were differentiated into myotubes in DMEM supplemented with 2 mM glutamine, 5% horse serum, 2% penicillin/streptomycin (5000 U) (Differentiation medium, DM). After 5-7 days in DM, spinal cord explants were added on the cultured contracting muscle cells. After co-culture with spinal cord, the culture was kept in DM. All co-cultures were fed three times a week and examined daily by phase-contrast inverted microscopy to check the appearance of the innervation.

[0091] Stimulation of the NMDARs was achieved by exposing cells to 100 μM NMDA, as previously described[14]. To

evaluate the CREB dependency, KG-501 (10 μM, Sigma) was added to the culture. After 5 days of treatment, explants were mechanically removed from the muscle layer, and proteins were purified and analyzed by western blot as described below.

Human primary culture of myogenic precursor cells from SMA patients biopsies

[0092] Muscle biopsies were obtained from the BTR (Bank of Tissues for Research, a partner in the EU network EuroBioBank) in accordance with European recommendations and French legislation. Satellite cells were isolated from biopsies and cultivated as described previously[26] in growth medium consisting of 1 vol 199 Medium / 4 vol DMEM (Invitrogen Life Technologies) supplemented with 20% fetal bovin serum (Invitrogen Life Technologies), 2.5 ng/ml hepatocyte growth factor (HGF) (Invitrogen Life Technologies), and 50μg/ml Gentamycin (Invitrogen Life Technologies). Further expansion was made in growth medium without HGF. The myogenic purity of the populations was monitored by immunocytochemistry using desmin as a marker. Differentiation was induced at confluence by replacing the growth medium with DMEM supplemented with 4% horse serum and 50μg/ml of gentamycin (Sigma). Specific blockade of MEK phosphorylation was achieved during 5 days using 10 μM of U0126 (Sigma).

Histological and immunohistochemical analysis.

[0093] Spinal cords were dissected and incubated overnight in 4% PFA PBS solution, and washed twice for 2 h with PBS. The lumbar spinal cords (L1 to L5) were embedded in 4% Agarose solution in sterilized water for 30 min at 4°C. 50 μm sections were then performed using a vibratome on the whole length of the sample. One out of every five sections was processed for immunohistochemical analysis. Tissue sections were incubated for 1 h at room temperature in a blocking solution (10% normal donkey serum with 0.5% Triton X-100 and 1% Tween in Tris Buffer Solution (TBS)). Motor neuron and Gemini of coiled bodies immunodetection were performed using a polyclonal goat anti-choline acetyltransferase (ChAT) primary antibody (1 : 400; Chemicon, Inc., Temecula, CA) and a monoclonal mouse anti-SMN primary antibody (1 : 200; BD Transduction Laboratories, Lexington, KY) for 4 days at 4°C in 3.5% donkey serum with 0.1% Tween TBS. Sections were washed between each subsequent step with 0.1% Tween in TBS. Sections were subsequently incubated with polyclonal Cy™3-conjugated Donkey anti-Goat antibodies (1 : 400; Jackson ImmunoResearch, West Grove, PA) and polyclonal Cy™2-conjugated Donkey anti-Mouse antibodies (1 : 400; Jackson ImmunoResearch) for 1 h at room temperature in 3.5% donkey serum with 0.1% Tween TBS. The sections were washed three times for 10 min in 0.1% Tween TBS and mounted in Fluoromount G™ (SouthernBiotech, Birmingham, AL) mounting medium. The staining specificity was checked in control incubations performed in the absence of the primary antibody.

[0094] All counts were performed using ImageJ software v1.37 (National Institutes of Health, Bethesda, MD). Color images were tinted using Image Pro-Plus software, where identical brightness, contrast, and color balance adjustments were applied to all groups.

Microscopy

[0095] All immunofluorescence images were collected with a CCD camera (QImaging Retiga 2000R Fast, Cooled Mono 12 bit) mounted on Olympus microscope (BX51) using the Image Pro-Plus v6.0 software (MediaCybernetics Inc., Bethesda, MD) with x40 (4X Olympus objective UPlan FL N 0.13), 100 (10X Olympus objective UPlan FL N 0.3), 200 (20X Olympus objective FL N 0.5), 400 (40X Olympus objective UPlan FL N 0.75), 600 (60X Olympus objective UPlanS Apo 1.35 oil) and 1000 (100X Olympus objective UPlanS Apo 1.4 oil) magnifications.

Protein and western blot analysis

[0096] Ventral lumbar spinal cord samples (2 to 5 mg) were homogenized in 100 μl/5 mg tissues of ice-cold RIPA buffer (50 mM Tris HCl pH=8.0, 150 mM NaCl, 0.1% SDS, 0.5% sodium deoxycholate, 1% NP40, 5 mM EDTA pH 8.0, 2 mM PMSF (phenyl-methylsulfonyl fluoride, Sigma-Aldrich), 50 μg/ml leupeptin, 50 μg/ml pepstatin A and 50 μg/ml aprotinin). Protein concentration of the clarified homogenates (4°C, 15 min, 13,500 rev.min-1) was determined on all samples using the Bradford protein assay (Biorad Laboratories, CA). 10 μg protein samples for SMN analysis and 30 μg samples for other analysis of each homogenate were submitted to 12.5% SDS-PAGE electrophoresis (1.5 M Tris pH 8.3, 12.5% Acrylamide, 0.07% Bis, 0.1% SDS, 0.05% APS, 0.06% TEMED). The separated proteins were transferred on PVDF membranes (Biorad) according to Towbin et al.[27]. Equal loading of samples was checked by Ponceau dye staining of the transferred gels. Western blot analysis was performed on membranes overnight at 4°C in 4% BSA, 0.05% TWEEN 20, TBS pH 7.4. Each of the following primary antibodies, including monoclonal mouse anti-SMN (1 : 5,000; Santa Cruz Biotechnology, Inc.), polyclonal rabbit anti-Ser473 phospho-AKT (1 : 1000; Cell signaling Technology, Inc, Boston, MA), polyclonal rabbit anti phospho-ERK1/2 (1 : 500; Cell Signaling, Inc.), polyclonal rabbit anti-Ser133 phospho-

CREB (1 : 1,000; Millipore), monoclonal mouse anti-Ser183 phospho-Elk-1 (1 : 1,000; Santa Cruz Biotechnology, Inc) was incubated overnight at 4°C in the above blocking medium. Membranes were rinsed in 0.1% TWEEN 20 in TBS for 3 x 10 min at room temperature and then incubated in horseradish peroxydase-conjugated Goat secondary antibody directed against Mouse Immunoglobulins (1 : 5,000; Biorad Laboratories, CA) and in horseradish peroxydase-conjugated Goat secondary antibody directed against Rabbit Immunoglobulins (1 : 10,000; Jackson ImmunoResearch) in 0.1 % TWEEN 20 in TBS for 1h at room temperature. Bound antibody complexes were developed using the ECL system (Amersham Biotech., Saclay, France) and exposed to hyperfilm ECL-plus X ray film (Amersham Biotech.).

[0097] In some instances, membranes were stripped after immunoblotting with phospho-AKT, phospho-ERK1/2, phospho-CREB and phospho-Elk-1 by incubation in stripping buffer (100 mM β-mercaptoethanol, 2% SDS, 62.5 mM Tris-HCl, pH 6.7) for 30 min at 55°C with agitation, and membranes were then blocked and reprobed with polyclonal rabbit anti-AKT (1 : 1,000; Cell Signaling, Inc.), polyclonal rabbit anti-ERK1/2 (1 : 500; Cell Signaling, Inc.), polyclonal rabbit anti-CREB (1 : 1,000; Millipore), monoclonal mouse anti-Elk-1 (1 : 1,000; Santa Cruz Biotechnology, Inc.) and monoclonal mouse anti-glyceraldehyde-3-phosphate dehydrogenase antibody (GAPDH) (1 : 5,000; Chemicon). Films were quantified with ImageJ v1.37 (National Institutes of Health, Bethesda, MD) and the results reported as means ± SEM.

Chromatin immunoprecipitation

[0098] Ventral lumbar Spinal Cord samples were chopped into small pieces with a scalpel and were fixed for 15 min with 1% formaldehyde. Tissues were washed 3 times in cold PBS containing protease inhibitors (2 mM PMSF, 50 μg/ml leupeptin, 50 μg/ml pepstatin A and 50 μg/ml aprotinin) and collected by centrifugation. Cell pellet were resuspended and incubated on ice for 10 min in 300 μl of lysis buffer (5 mM piperazine-N,N'-bis(2-ethanosulfonic acid) (PIPES) pH 8.0, 85 mM KCL, 0.5% NP-40) and protease inhibitors. Cells were pelleted by centrifugation and resuspended in 300 μl of 1% SDS, 10mM EDTA and 50 mM Tris-HCL (pH 8.0) containing protease inhibitors. After incubation on ice for 10 min, cells were sonicated 6 times for 30 sec using Bioruptor (Diagenode, Philadelphia, PA). Lysates were cleared by centrifugation and DNA concentration was determined using a nanodrop spectrophotometer. ChIP-Adembeads (Ademtech SA, Pessac, France) were incubated for 15 min at room temperature with blocking buffer on a rotating wheel. Beads were ressuspended in 125 μl of ChIP Dilution buffer (0.01% SDS, 1% Triton X100, 1.2mM EDTA, 16.7 mM Trid-HCl (pH 8.1)), and after a 1h incubation, equal amounts of DNA diluted 10 times in dilution buffer were added. DNA was incubated overnight at 4°c on a rotating wheel with 1 μg of the following antibodies: polyclonal rabbit anti-Ser133 phospho-CREB (Millipore), monoclonal mouse anti-Ser183 phospho-Elk-1 (Santa Cruz Biotechnology, Inc), polyclonal rabbit anti-acetyl-Histone H3 Lys9 (Millipore) and polyclonal rabbit-acetyl-Histone H4 Lys 8 (Upstate Biotechnology, Inc., Lake Placid, NY). Beads were washed sequentially in TSE (0.1% SDS, 1% Triton X100, 2mM EDTA, 20 mM Tris-HCl (pH 8.1) with 150 mM NaCl, TSE with 500 mM NaCl, buffer A (0.25 M LiCl, 1% NP-40, 1% deoxycholate, 1 mM EDTA, 10 mM Tris-Hcl (pH 8.1), and 2 times with tris-EDTA and then eluted with 200 μl 1% SDS and 0.1 M NaHCO3. Cross-links were reversed by heating at 65°C for 4 h after adding NaCl to 200 mM final concentration. After treatment with proteinase K (50μg/ml) for 1 h at 37°C, DNA was purified using Geneclean Turbo Kit (Q-Biogene, MP Biomedicals, Illkirch, France). Real time PCR analysis of inputs or immunoprecipitated DNAs was performed.

Quantitative real time PCR analysis

[0099] Quantitative real time PCR was performed with standard protocols using SYBR®Green ROX Mix (ABgene, Courtaboeuf, France) as a fluorescent detection dye in ABI PRISM® 7000 in a final volume of 10 μl which also contains 300 nM of primers (Operon, Cologne, Germany).

[0100] The relative amounts of DNA in samples were determined on the basis of the threshold cycle for each PCR product (Ct).

Statistical analysis.

[0101] All values are displayed as means and standard error of the mean (SEM) within each group (Systat v 8.0, SPSS Inc., Chicago, IL). Statistical analysis was performed and comparison between groups were done using ANOVA and post-hoc test LSD. Survival analysis was performed using Kaplan-Meier analysis.

Results

[0102] The mode of action of therapeutic molecules for the treatment of SMA may include the increase of SMN expression particularly in motor neurons through activating the SMN2 promoter, increasing exon-7 inclusion in SMN transcripts, or extending the half-life of SMN mRNA or protein. It may also include the promotion of motor neuron survival through the activation of anti-apoptotic pathways. Over the years, a number of groups have identified SMN2 gene-

inducing compounds using cultured fibroblasts derived from SMA patients, and which benefits were often further tested in vivo in SMA mouse models[5]. Among those, SMN inducer compounds were identified based on their supposed ability to increase general gene expression, such as histone deacetylase inhibitors[6, 7, 8], or by high throughput screenings, such as quinazoline derivatives[9, 10]. Unfortunately, to date, many of these compounds were disappointing in clinical trials with no substantial clinical benefit demonstrated[11, 12, 13]. Ultimately, none of these compounds provide efficient anti-apoptotic potential for motor neurons.

[0103] One promising, as yet unexplored, therapeutic development for SMA could involve the pharmacological correction of molecular mechanisms, specifically altered in SMA neuromuscular system, potentially capable of modulating either SMN expression, or motor-neuron survival or both. In this context, the inventors paid further attention to the activation pattern of the AKT/CREB signalling pathway. Constitutively down-regulated in mouse SMA spinal cord, the AKT/CREB pathway is able to remarkably alleviate SMA symptoms in mice as long as it is reactivated[14]. In very severe SMA-like mice[15], the reactivation of AKT/CREB pathway by NMDA resulted in an increased in the total amount of SMN transcripts in the SMA spinal cord without modifying its splicing pattern suggesting a SMN2 gene regulation at the transcriptional level[14]. Furthermore, considered as a common and powerful antiapoptotic pathway[16] notably for spinal motor neurons[17], the AKT/CREB pathway activation likely represents an important clue for motor neuron resistance to cell death in SMA spinal cord. Thus, identifying therapeutic agents that could lead to the reactivation of the AKT/CREB pathway in SMA spinal cord is of a paramount importance.

[0104] Interestingly, the activation profile of another major intracellular signaling pathway in neurons[18], namely the ERK1/2 signaling pathway, was in opposite contrast to that of AKT in SMA spinal cord. Constitutively over-activated in the spinal cord of two different severe mouse models of SMA, characterized by a weak SMN expression, ERK1/2 was inhibited when AKT is reactivated and this change in ERK/AKT activation balance correlated with an increase in SMN expression[14]. These data raise important questions regarding 1) the respective roles of ERK and AKT pathways in modulating SMN2 gene expression and 2) the potential cross relationships in the activation profile of these two signaling pathways in SMA spinal cord.

[0105] Interestingly, the sequence analysis of the human SMN promoter (GenBank accession AF187725) revealed that several CREB binding sites are flanked by putative response elements for transcription factors that are direct target of ERK[19, 20, 21], namely the transcription factors of the ETS family Elk-1 (Fig. 1a-b). Yet, the CREB binding site 2 (+244 to +248 bp), considered as a positive regulator of SMN gene expression[22], contains also putative response elements for Elk-1 (+356 to +429 bp), including a binding site for the Serum Response Factor (SRF). We identified an additional putative CRE site, which we named site 1, that includes two putative CREB binding sites (-2572 to -2569 bp and -2525 to -2522 bp) also containing putative SRF binding site (-2556 to -2548 bp). ChIP experiments showed that the two transcription factors effectively bound to the two CRE sites but with an efficacy that correlated to their levels of activation. Elk-1, over-activated in the spinal cord of type 1 SMA-like mice (Fig. 1c-d), as expected for a direct target of ERK, displayed an increased binding on the two CRE sites in SMA spinal cord compared to controls (Fig. 1e-f). In contrast, ChIP experiments revealed a dramatic decrease in the binding of CREB to the two CRE sites (Fig. 1g-h). Interestingly, the ratio of CREB and Elk-1 binding on the CRE sites was completely reversed in SMA spinal cords when SMN expression is promoted i.e. after a direct NMDA-receptor activation (Fig. 1e-h). To gain further insight into the potential role of Elk-1 in the control of SMN2 gene expression, we analysed by ChIP the acetylation profiles of histones H3 and H4 in the two CRE sites in the spinal cord of SMA and control mice. Elk-1 recruitment to the two CRE sites correlated to a marked decrease of H3 and H4 acetylation, compared to controls, whereas CREB recruitment induced a marked increase of H3 and H4 acetylation (Fig. 1i-1). Taken together, these results suggested that the ERK/Elk-1 pathway activation resulted in the repression of SMN2 gene expression in SMA spinal cord, contrasting with the results found in a non SMA neuronal context[23].

[0106] Therefore, it could be speculated that inhibiting the ERK pathway would abolish the Elk-1-induced inhibition of SMN2 gene transcription and would lead consequently to an increase of SMN expression in SMA spinal cord. To test this hypothesis, a population of type 1 SMA-like mice was treated daily from birth by intrathecal injection of U0126, a specific MAPK Kinase (MEK) inhibitor. The in vivo ERK inhibition, that induced a marked decrease of Elk-1 activation in SMA (Fig. 2a-b), resulted in a remarkable increase in SMN protein concentration in the spinal cord of type 1 SMA-like mice (Fig. 2c-d). These data are further emphasized by the significant increase of gemini of coiled bodies (gems) in the motor-neuron nuclei of U0126-treated SMA-like mice (data not shown and Fig. 2e). Unexpectedly, the ERK inhibition resulted in a significant activation of AKT (Fig 2f-g) and CREB (Fig 2h-i) in SMA spinal cord, likely acting synergistically with the Elk-1 inhibition to increase SMN expression. Consistent with our findings in SMA-like mice, the inhibition of the ERK pathway by U0126 in myotube culture of paravertebral muscles from type 2 SMA patient resulted in a significant increase of SMN expression (Fig. 2j-k).

[0107] In order to substantiate this crosstalk hypothesis at the level of the kinases ERK and AKT in the signaling cascades, we tested in vitro the effects of CREB inhibition on the ERK/Elk-1 pathway activation profile in a SMA context in which the AKT pathway was significantly activated i.e. following NMDA-receptor activation. We found that CREB inhibition resulted in the activation of ERK1/2 (Fig. 3a-b) and Elk-1 (Fig. 3c-d) as hypothesized. More surprisingly, the

CREB inhibition resulted in a significant inhibition of the AKT (Fig. 3e-f), suggesting a negative feedback from the transcription factor to its activating kinase. The concomitant activation of the ERK/Elk-1 pathway and inhibition of the AKT/CREB pathway expectedly resulted in a significant decrease in SMN expression (Fig. 3g-h). Taken together, these data strongly suggest the existence of a dynamic equilibrium between ERK and AKT pathways in SMA spinal cord. This equilibrium could be displaced by reciprocal blockades, opening thus a promising way for reactivating the AKT/CREB pathway in SMA spinal cord.

[0108] Finally, in vivo ERK inhibition resulted in a remarkable improvement in the phenotype and survival of severe SMA-like mice compared to vehicle-treated counterparts. The mean survival increased from 1.60 $\pm$ 0.48 days for the vehicle-treated SMA-like mice to 4.13 $\pm$ 1.07 days for the U0126-treated mice (Fig. 4a), representing a 2.5 fold increase in lifespan ($p<0.01$), which remains, to date, the best pharmacological treatment ever reported in this SMA mouse model. In addition, the U0126 treatment led to a significant and progressive increase in the body weight of SMA-like mice, until death (Fig. 4b). These benefits were associated with the significant increase in the number and the surface of motor-neuron in lumbar spinal cord of U0126-treated SMA-like mice compared to placebos (Fig. 4c-h).

[0109] These results prompted us to test whether a pre-approved MEK inhibitor could provide the same effects of U0126 on SMN expression and severe SMA-like mouse lifespan. We chose to test a new drug, Selumetinib (AZD6244), a well known specific MEK inhibitor, which is currently in phase II clinical trial[4], successfully tested in the Pediatric Preclinical Testing[24]. Expectedly, oral Selumetinib treatment reproduced the effects obtained with U0126, including an activation of SMN expression in the spinal cord of SMA mice (Fig. 4i-j), an activation of AKT (Fig. 4k-l) and a remarkable increase in the life span of SMA mice (Fig. 4m) associated with a progressive gain of body weight (Fig. 4n).

[0110] Taken together, all these results indicate that the pharmacological inhibition of ERK pathway, notably through the use of Selumetinib, could be considered as an efficient treatment to alleviate SMA symptoms in patients.

REFERENCES

[0111]

1- Crawford, T.O. & Pardo, C.A. The neurobiology of childhood spinal muscular atrophy. Neurobiol. Dis. 3, 97-110 (1996).

2- Lefebvre, S. et al. Identification and characterization of a spinal muscular atrophy-determining gene. Cell 80, 155-165 (1995).

3- Lorson, C.L. & Androphy, E.J. An exonic enhancer is required for inclusion of an essential exon in the SMA-determining gene SMN. Hum. Mol. Genet. 9, 259-265 (2000).

4- Board, R.E. et al. Detection of BRAF mutations in the tumour and serum of patients enrolled in the AZD6244 (ARRY-142886) advanced melanoma phase II study. Br. J. Cancer 101, 1724-1730 (2009).

5- Lorson, C.L., Rindt, H. & Shababi, M. Spinal muscular atrophy: mechanisms and therapeutic strategies. Hum. Mol. Genet. 19, R111-118 (2010).

6- Chang, J.G. et al. Treatment of spinal muscular atrophy by sodium butyrate. Proc. Natl. Acad. Sci. U. S. .A. 98, 9808-9813 (2001).

7- Avila, A.M. et al. Trichostatin A increases SMN expression and survival in a mouse model of spinal muscular atrophy. J. Clin. Invest. 117, 659-671 (2007).

8- Tsai, L.K., Tsai, M.S., Ting, C.H. & Li, H. Multiple therapeutic effects of valproic acid in spinal muscular atrophy model mice. J. Mol. Med. 86, 1243-1254 (2008).

9- Thurmond, J. et al. Synthesis and biological evaluation of novel 2,4-diaminoquinazoline derivatives as SMN2 promoter activators for the potential treatment of spinal muscular atrophy. J. Med. Chem. 51, 449-469 (2008).

10- Butchbach, M.E. et al. Effect of diet on the survival and phenotype of a mouse model for spinal muscular atrophy. Biochem. Biophys. Res. Commun. 391, 835-840 (2010).

11- Mercuri, E. et al. Randomized, double-blind, placebo-controlled trial of phenylbutyrate in spinal muscular atrophy. Neurology 68, 51-55 (2007).

12- Swoboda, K.J. et al. Phase II open label study of valproic acid in spinal muscular atrophy. PLoS One 4, e5268. (2009).

13- Swoboda, K.J. et al. Project Cure Spinal Muscular Atrophy Investigators Network. SMA CARNI-VAL trial part I: double-blind, randomized, placebo-controlled trial of L-carnitine and valproic acid in spinal muscular atrophy. PLoS One 5, e12140 (2010).

14- Biondi, O. et al. In vivo NMDA receptor activation accelerates motor unit maturation, protects spinal motor neurons, and enhances SMN2 gene expression in severe spinal muscular atrophy mice. J. Neurosci. 30, 11288-11299 (2010).

15- Monani, U.R. et al. The human centromeric survival motor neuron gene (SMN2) rescues embryonic lethality in Smn(-/-) mice and results in a mouse with spinal muscular atrophy. Hum. Mol. Genet. 9, 333-339 (2000).

16- Dudek, H. et al. Regulation of neuronal survival by the serine-threonine protein kinase AKT. Science 275, 661-665 (1997).
17- Soler, R.M. et al. Receptors of the glial cell line-derived neurotrophic factor family of neurotrophic factors signal cell survival through the phosphatidylinositol 3-kinase pathway in spinal cord motoneurons. J. Neurosci. 19, 9160-9169 (1999).
18- Xia, Z., Dickens, M., Raingeaud, J., Davis, R.J., Greenberg, M.E. Opposing effects of ERK and JNK-p38 MAP kinases on apoptosis. Science 270, 1326-1331 (1995).
19- Whitmarsh, A.J., Shore, P., Sharrocks, A.D. & Davis, RJ. Integration of MAP kinase signal transduction pathways at the serum response element. Science 269, 403-407 (1995).
20- Yang, S.H., Shore, P., Willingham, N., Lakey, J.H. & Sharrocks, A.D. The mechanism of phosphorylation-inducible activation of the ETS-domain transcription factor Elk-1. EMBO J. 18, 5666-5674 (1999).
21- Zhang, H.M. Mitogen-induced recruitment of ERK and MSK to SRE promoter complexes by ternary complex factor Elk-1. Nucleic Acids Res. 36, 2594-2607 (2008).
22- Majumder, S. et al. Identification of a novel cyclic AMP-response element (CRE-II) and the role of CREB-1 in the cAMP-induced expression of the survival motor neuron (SMN) gene. J. Biol. Chem. 279, 14803-14811 (2004).
23- Demir, O. et al. ETS-domain transcription factor Elk-1 mediates neuronal survival: SMN as a potential target. Biochim. Biophys. Acta 1812, 652-662. (2011).
24- Kolb, E.A, et al. Initial testing (stage 1) of AZD6244 (ARRY-142886) by the Pediatric Preclinical Testing Program. Pediatr. Blood Cancer 55, 668-677 (2010).
25- Kobayashi, T., Askanas, V. & Engel, W.K. Human muscle cultured in monolayer and cocultured with fetal rat spinal cord: importance of dorsal root ganglia for achieving successful functional innervation. J. Neurosci. 7, 3131-3141 (1987).
26- Bigot, A. et al. Large CTG repeats trigger p16-dependent premature senescence in myotonic dystrophy type 1 muscle precursor cells. Am. J. Pathol. 174, 1435-1442 (2009).
27- Towbin, H., Schoenenberger, C., Ball, R., Braun, D.G. & Rosenfelder, G. Glycosphingolipid-blotting: an immunological detection procedure after separation by thin layer chromatography. J. Immunol. Methods. 72, 471-479 (1984).

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Claims

1. An ERK inhibitor for use in treating spinal muscular atrophy associated to a deficiency in a Survival-Motor-Neuron (SMN) gene, said deficiency resulting in loss of motor function, wherein said ERK inhibitor is a compound which inhibits MEK ERK1/2 signaling activity as measured by the relative amount of phosphorylated ERK proteins or Elk1 protein.

2. The ERK inhibitor for use according to Claim 1, wherein said deficiency resulting in loss of motor function is a genetic mutation in SMN1 gene.

3. The ERK inhibitor for use according to any one of Claims 1-2, wherein said ERK inhibitor is a MEK1/2 inhibitor, preferably with an IC50 of at least μM, or less.

4. The ERK inhibitor for use according to Claim 3, wherein said MEK1/2 inhibitor is selected from the group consisting of selumetinib, U0126, PD98059, PD0325901, AZD8330, CI-1040 and PD318088.

5. The ERK inhibitor for use according to Claim 3, wherein said ERK inhibitor is selected from the group consisting of selumetinib and its derivatives and pharmaceutically acceptable salts thereof.

6. The ERK inhibitor for use according to any one of Claims 1-2, wherein said ERK inhibitor is selected from the group consisting of nucleic acid molecule such as siRNA, shRNA and anti-sense oligonucleotide, said nucleic acid molecule being capable of reducing the expression of MEK1, MEK2, ERK1 or ERK2.

7. The ERK inhibitor for use according to any one of Claims 1-6, wherein said ERK inhibitor is administered orally to

a subject in an amount effective to treat spinal muscular atrophy.

8. A pharmaceutical composition comprising an ERK inhibitor, in combination with another active principle ingredient selected from the group consisting siRNA, shRNA or antisense compounds directed against nucleic acid encoding a deficient SMN1 gene product resulting in loss of motor function, wherein said ERK inhibitor is a compound which inhibits MEK ERK1/2 signaling activity as measured by the relative amount of phosphorylated ERK proteins or Elk1 protein.

Patentansprüche

1. ERK-Inhibitor zur Verwendung bei der Behandlung von spinaler Muskelatrophie, die mit einem Mangel in einem Motorneuronlebenserhaltungsgen (SMN-Gen) assoziiert ist, wobei der Mangel in einem Verlust der motorischen Funktion resultiert, wobei der ERK-Inhibitor eine Verbindung ist, welche die MEK, ERK 1/ 2-Siganlisierungsaktivität, die durch die relative Menge an phosphoryliertem ERK-Protein oder Elk1-Protein gemessen wird, hemmt.

2. ERK-Inhibitor zur Verwendung nach Anspruch 1, wobei der Mangel, der in einem Verlust der motorischen Funktion resultiert, eine genetische Mutation des SMN1-Gens ist.

3. ERK-Inhibitor zur Verwendung nach einem der Ansprüche 1-2, wobei der ERK-Inhibitor ein MEK1/2-Inhibitor ist, vorzugsweise mit einem IC50 von mindestens 1 μm oder weniger.

4. ERK-Inhibitor zur Verwendung nach Anspruch 3, wobei der MEK1/2-Inhibitor aus der Gruppe ausgewählt ist, die aus Selumetinib, U0126, PD98059, PD0325901, AZD8330, C1-1040 und PD318088 besteht.

5. ERK-Inhibitor zur Verwendung nach Anspruch 3, wobei der ERK-Inhibitor aus der Gruppe ausgewählt ist, die aus Selumetinib und seinen Derivaten und pharmazeutisch unbedenklichen Salzen davon besteht.

6. ERK-Inhibitor zur Verwendung nach einem der Ansprüche 1-2, wobei der ERK-Inhibitor aus der Gruppe ausgewählt ist, die aus Nukleinsäuremolekül wie siRNA, shRNA und Antisense-Oligonukleotid besteht, wobei das Nukleinsäuremolekül in der Lage ist, die Expression von MEK1, MEK2, ERK1 oder ERK2 zu reduzieren.

7. ERK-Inhibitor zur Verwendung nach einem der Ansprüche 1-6, wobei der ERK-Inhibitor einem Subjekt oral in einer Menge verabreicht wird, die zum Behandeln von spinaler Muskelatrophie wirksam ist.

8. Pharmazeutische Zusammensetzung, umfassend einen ERK-Inhibitor in Kombination mit einem anderen Wirkstoff, der aus der Gruppe ausgewählt ist, die aus siRNA, shRNA oder Antisense-Verbindungen besteht, die sich gegen Nukleinsäure richten, die ein defizientes SMN1- Genprodukt codiert, das im Verlust der motorischen Funktion resultiert, wobei der ERK-Inhibitor eine Verbindung ist, welche die MEK, ERK1/2-Signalisierungsaktivität, die von der relativen Menge von phosphorylierten ERK-Proteinen oder Elk1-Protein gemessen wird, hemmt.

Revendications

1. Inhibiteur de ERK pour une utilisation dans le traitement de l'amyotrophie spinale associée à une anomalie dans le gène de survie des neurones moteurs (SMN), ladite anomalie entraînant une perte de la fonction motrice, ledit inhibiteur de ERK étant un composé qui inhibe l'activité de signalisation de MEK-ERK1/2 mesurée par la quantité relative des protéines ERK ou de la protéine Elk1 phosphorylées.

2. Inhibiteur de ERK pour une utilisation selon la revendication 1, ladite anomalie entraînant une perte de la fonction motrice étant une mutation génétique dans le gène SMN1.

3. Inhibiteur de ERK pour une utilisation selon l'une des revendications 1 et 2, ledit inhibiteur de ERK étant un inhibiteur de MEK1/2, de préférence avec une CI50 d'au moins 1 μM, ou inférieure.

4. Inhibiteur de ERK pour une utilisation selon la revendication 3, ledit inhibiteur de MEK1/2 étant choisi dans le groupe constitué du sélumétinib, U0126, PD98059, PD0325901, AZD8330, CI-1040 et PD318088.

5. Inhibiteur de ERK pour une utilisation selon la revendication 3, ledit inhibiteur de ERK étant choisi dans le groupe constitué du sélumétinib et de ses dérivés et de leurs sels pharmaceutiquement acceptables.

6. Inhibiteur de ERK pour une utilisation selon l'une quelconque des revendications 1 et 2, ledit inhibiteur de ERK étant choisi dans le groupe constitué d'une molécule d'acide nucléique telle qu'un ARNsi, un ARNsh et un oligonucléotide antisens, ladite molécule d'acide nucléique étant capable de réduire l'expression de MEK1, MEK2, ERK1 ou ERK2.

7. Inhibiteur de ERK pour une utilisation selon l'une quelconque des revendications 1 à 6, ledit inhibiteur de ERK étant administré par voie orale à un sujet dans une quantité efficace pour traiter l'amyotrophie spinale.

8. Composition pharmaceutique comprenant un inhibiteur de ERK, en combinaison avec un autre composant de principe actif choisi dans le groupe constitué d'un ARNsi, un ARNsh ou des composés antisens dirigés contre l'acide nucléique codant pour un produit déficient du gène SMN1 entraînant une perte de la fonction motrice, dans laquelle ledit inhibiteur de ERK est un composé qui inhibe l'activité de signalisation de MEK-ERK1/2 mesurée par la quantité relative des protéines ERK ou de la protéine Elk1 phosphorylées.

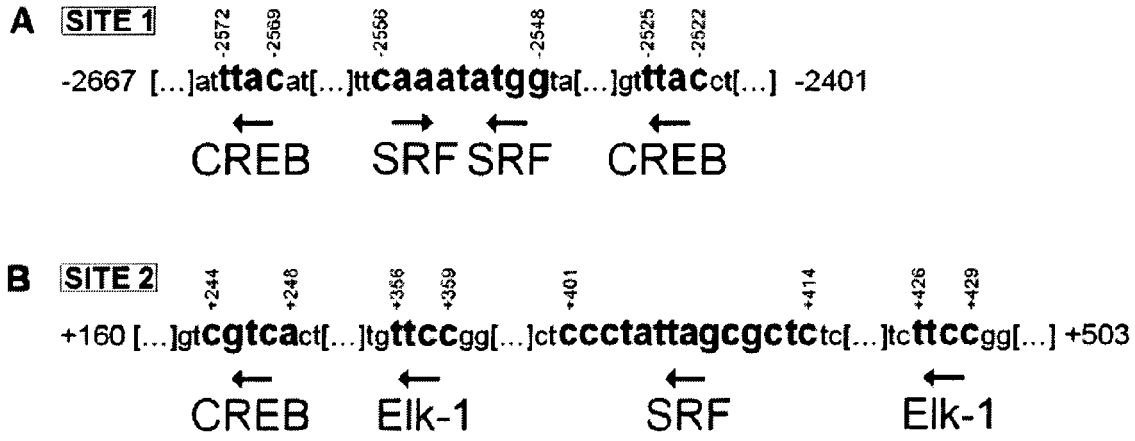
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Figure 1

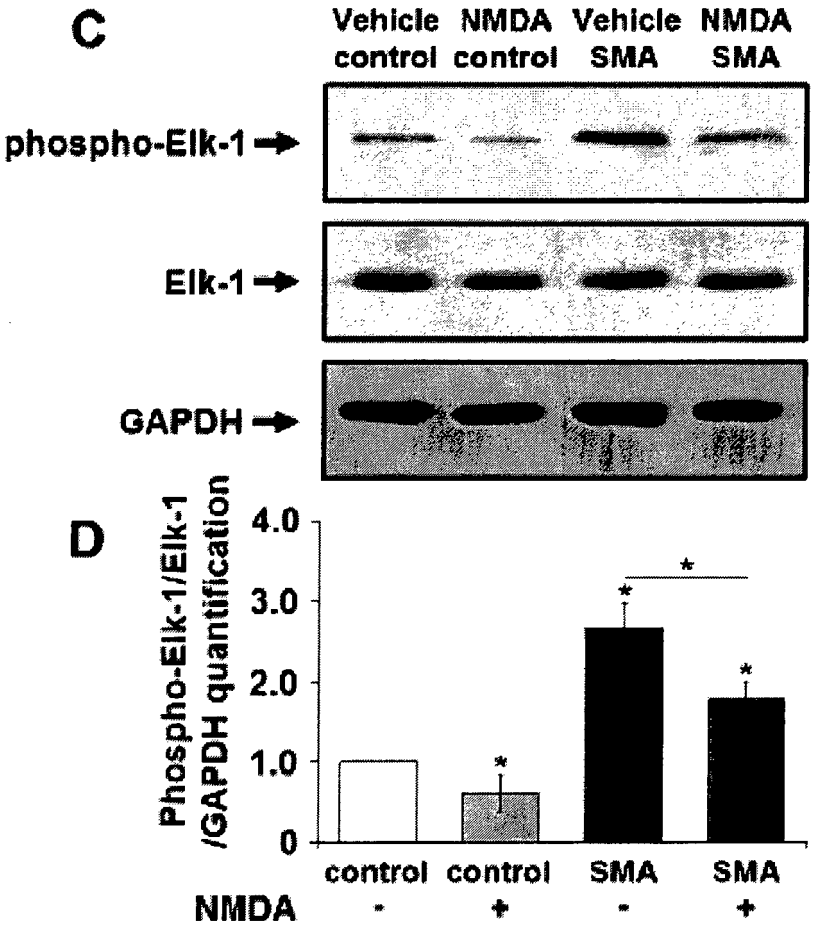
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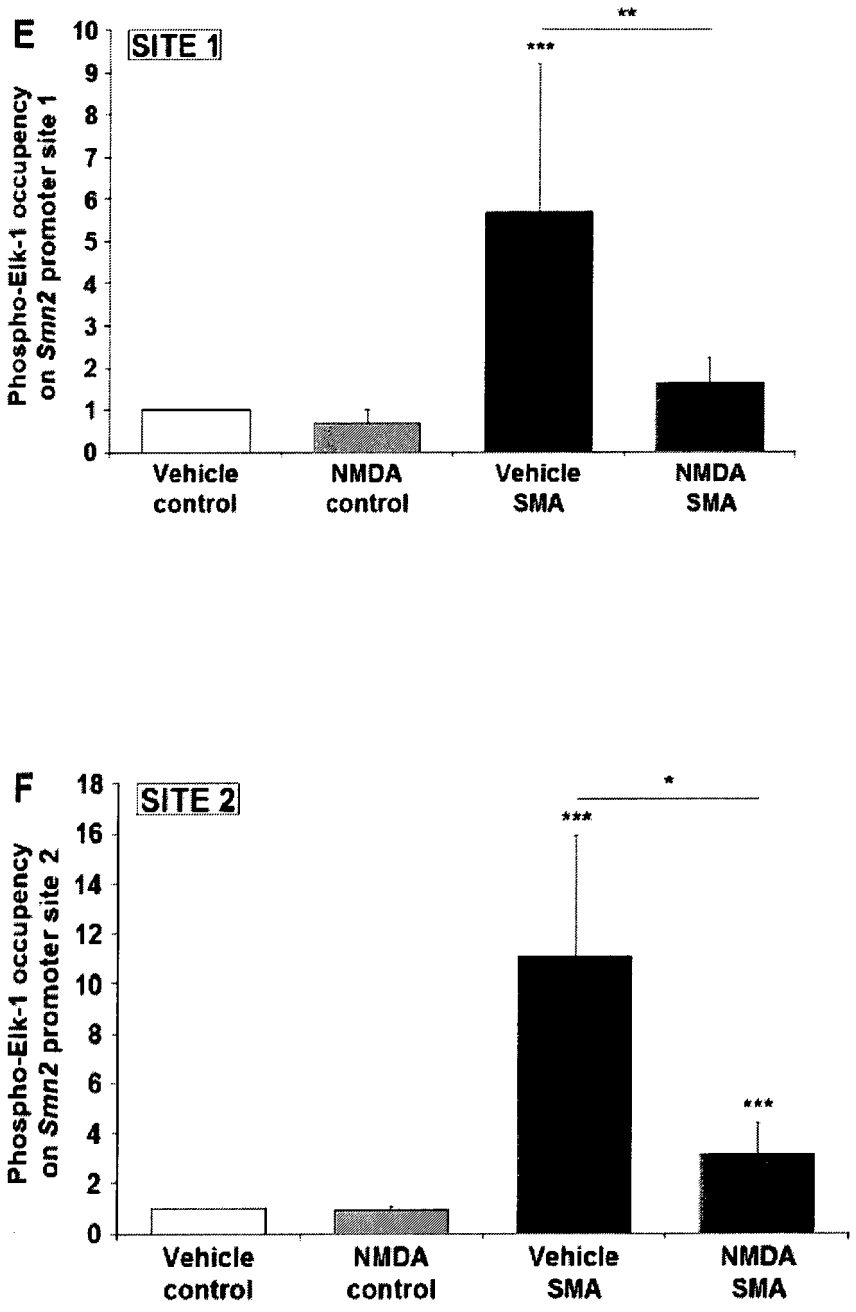
Figure 1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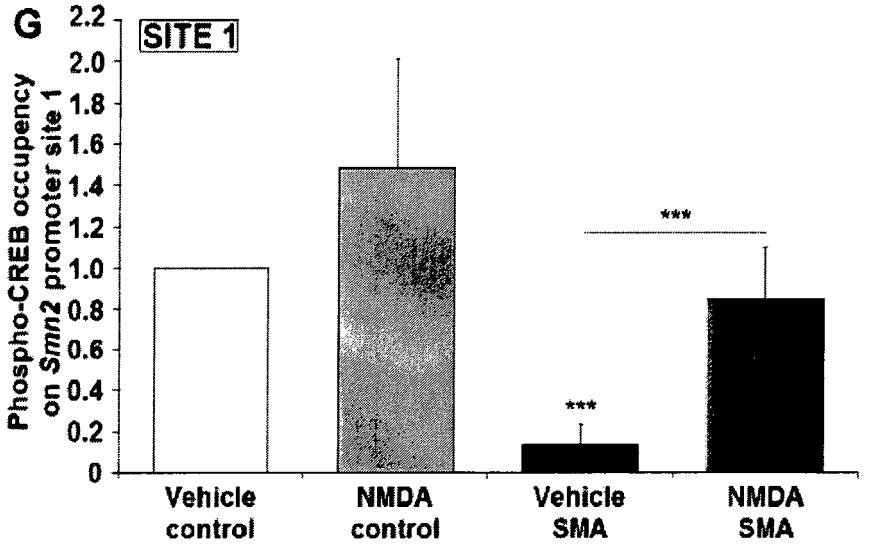
NMDA SMA
F
SITE 2
Phospho-Elk-1 occupency on Smn2 promoter site 2
18
16
14
12
10
8
6
4
2
0
*
***
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA

FIGURE 1


G
SITE 1
Phospho-CREB occupency on Smn2 promoter site 1
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
***
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA

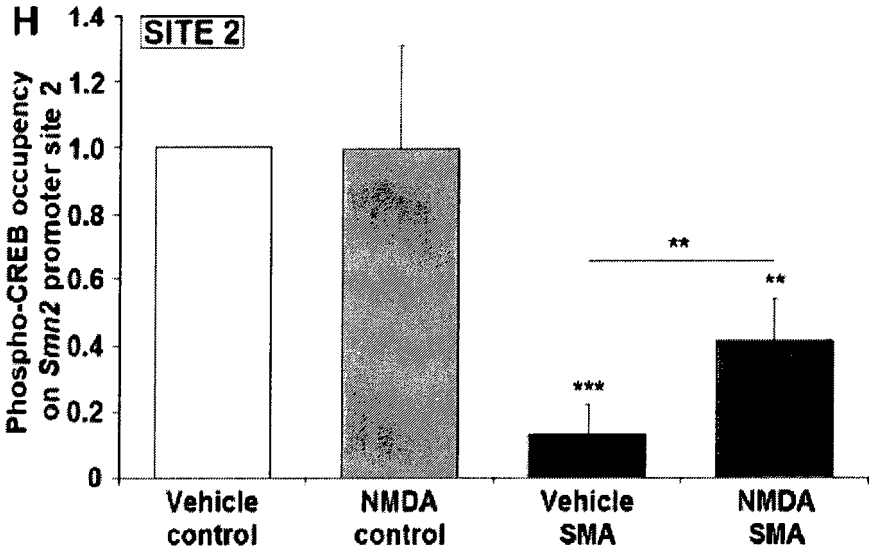

H
SITE 2
Phospho-CREB occupency on Smn2 promoter site 2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
**
**
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA

FIGURE 1

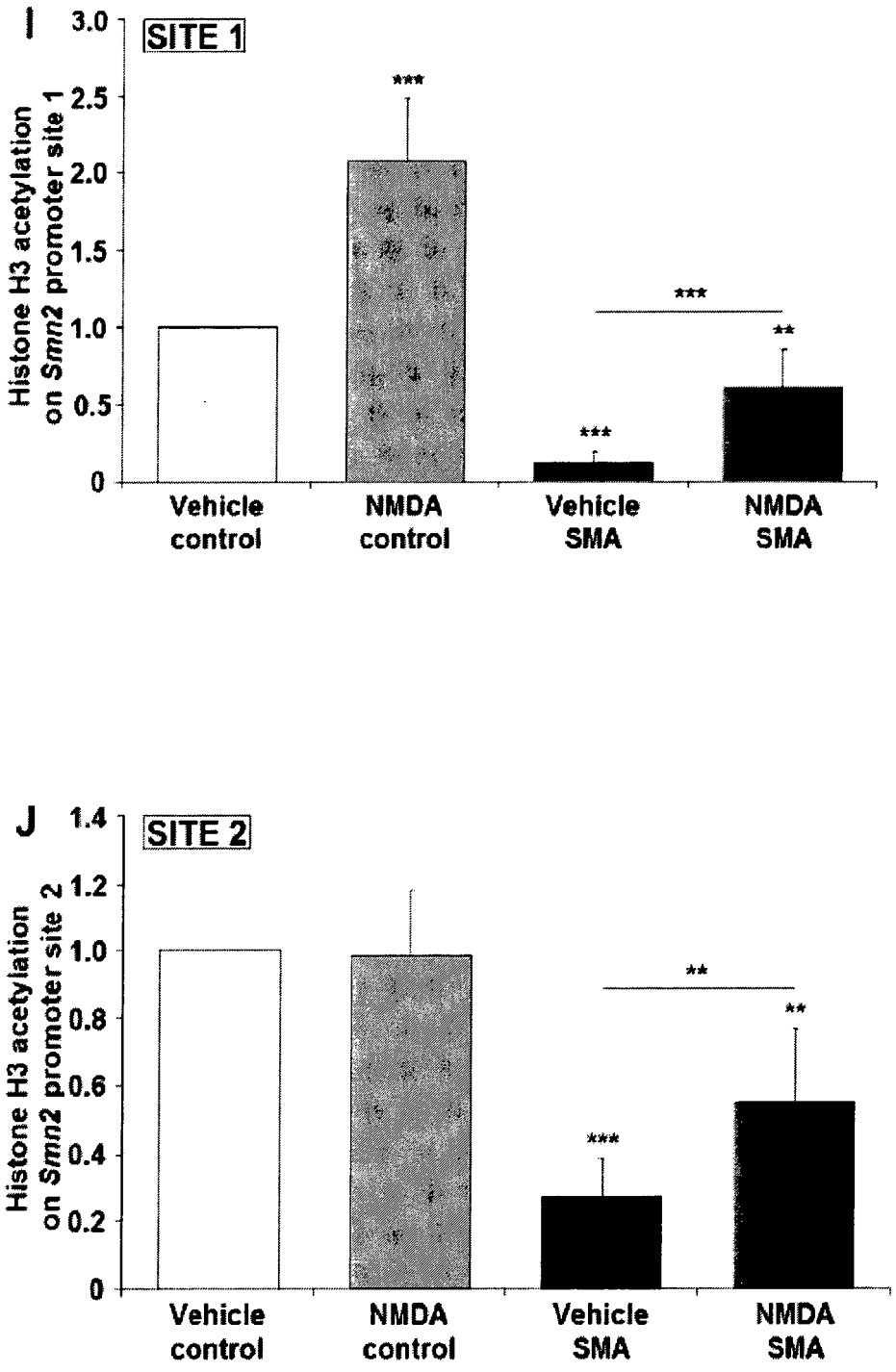

I
SITE 1
Histone H3 acetylation on Smn2 promoter site 1
3.0
2.5
2.0
1.5
1.0
0.5
0
***
***
**
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA
J
SITE 2
Histone H3 acetylation on Smn2 promoter site 2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
**
**
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA

FIGURE 1

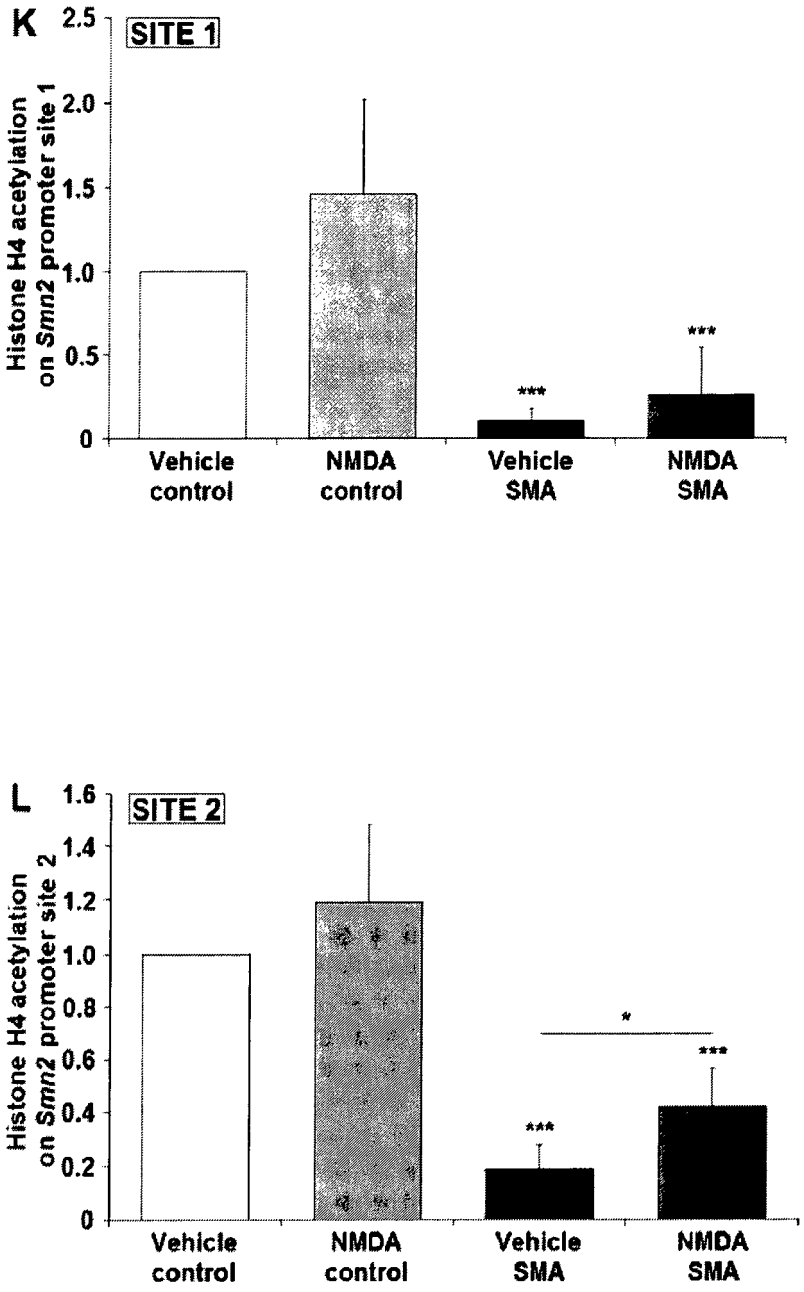

K
SITE 1
Histone H4 acetylation on Smn2 promoter site 1
2.5
2.0
1.5
1.0
0.5
0
***
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA
L
SITE 2
Histone H4 acetylation on Smn2 promoter site 2
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
*
***
***
Vehicle control
NMDA control
Vehicle SMA
NMDA SMA

FIGURE 1

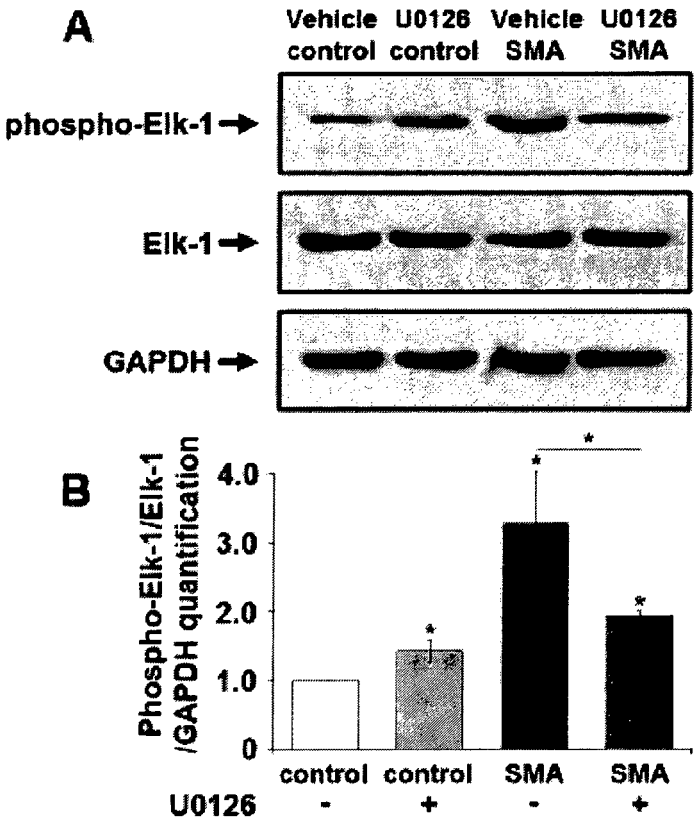

A
Vehicle control
U0126 control
Vehicle SMA
U0126 SMA
phospho-Elk-1
Elk-1
GAPDH
B
Phospho-Elk-1/Elk-1 /GAPDH quantification
4.0
3.0
2.0
1.0
0
control
control
SMA
SMA
U0126
-
+
-
+

Figure 2

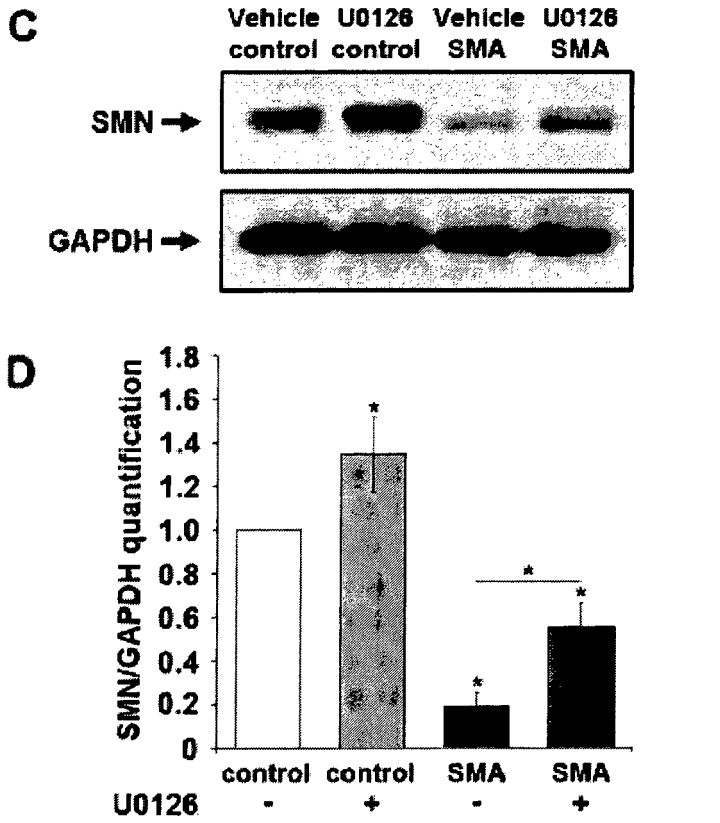

C
Vehicle control
U0126 control
Vehicle SMA
U0126 SMA
SMN
GAPDH
D
SMN/GAPDH quantification
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
control
control
SMA
SMA
U0126
-
+
-
+
E
Number of GEMS/motor neuron
3.0
2.0
1.0
0
control
control
SMA
SMA
U0126
-
+
-
+

FIGURE 2

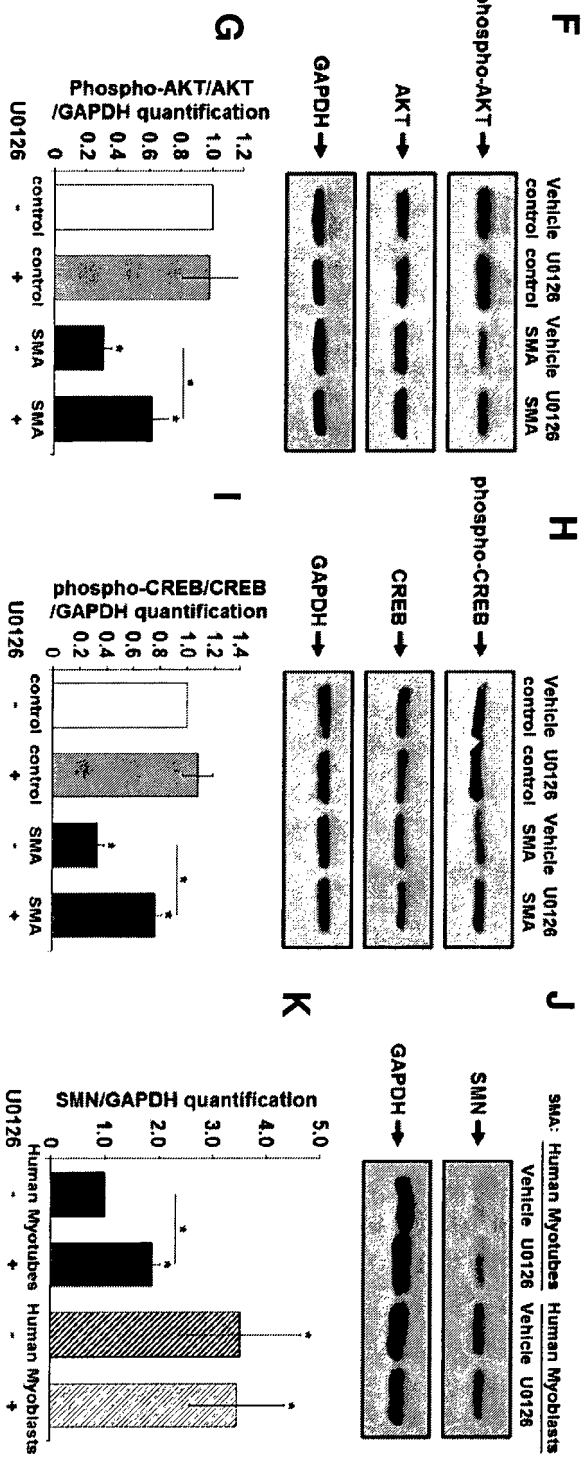

F
phospho-AKT
AKT
GAPDH
Vehicle control
U0126 control
Vehicle SMA
U0126 SMA
G
Phospho-AKT/AKT /GAPDH quantification
0 0.2 0.4 0.6 0.8 1.0 1.2
U0126
control
SMA
H
phospho-CREB
CREB
GAPDH
I
phospho-CREB/CREB /GAPDH quantification
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
J
SMN
GAPDH
SMA: Human Myotubes Human Myoblasts
Vehicle U0126 Vehicle U0126
K
SMN/GAPDH quantification
0 1.0 2.0 3.0 4.0 5.0
Human Myotubes
Human Myoblasts

Figure 2

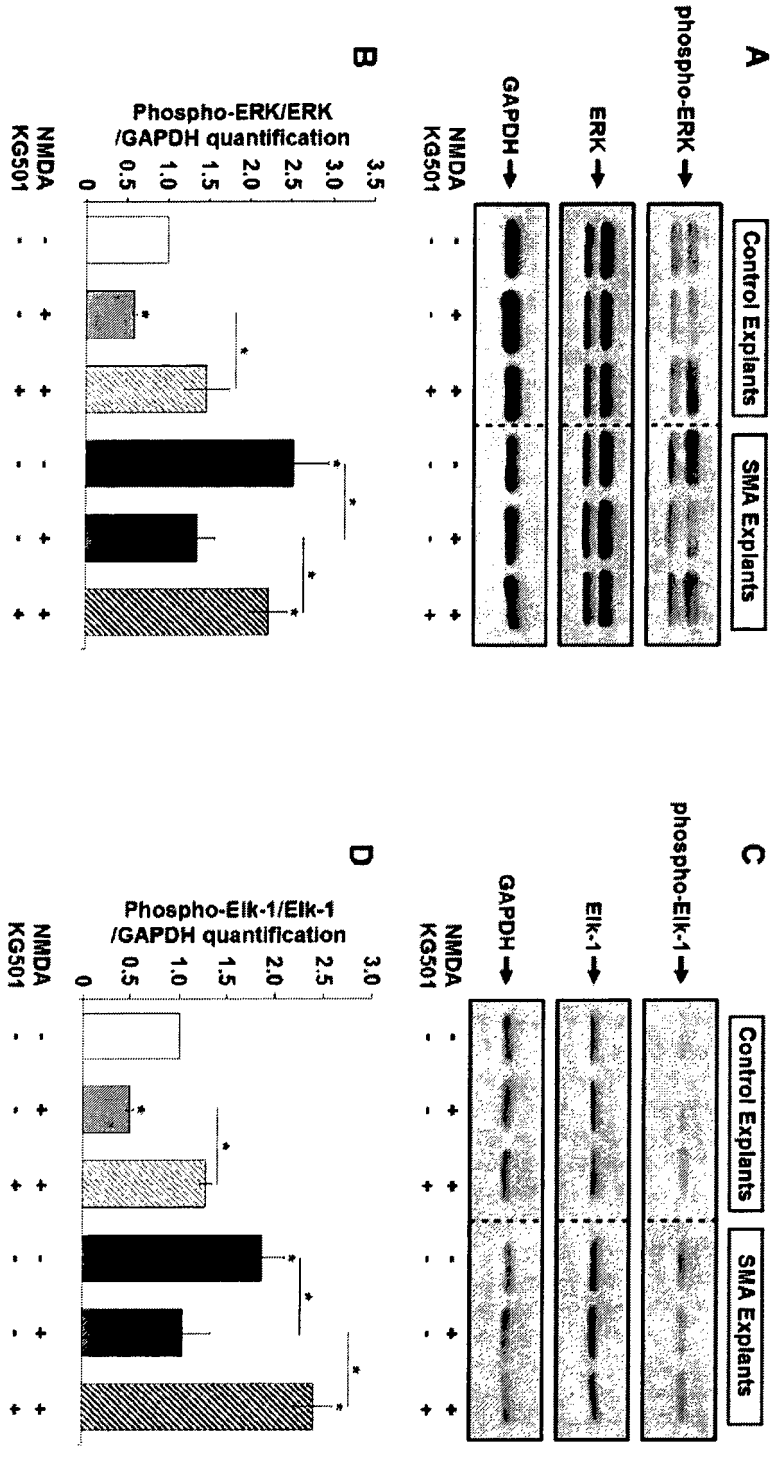

A
phospho-ERK
ERK
GAPDH
NMDA
KG501
Control Explants
SMA Explants
B
Phospho-ERK/ERK
/GAPDH quantification
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
C
phospho-Elk-1
Elk-1
D
Phospho-Elk-1/Elk-1
/GAPDH quantification

Figure 3

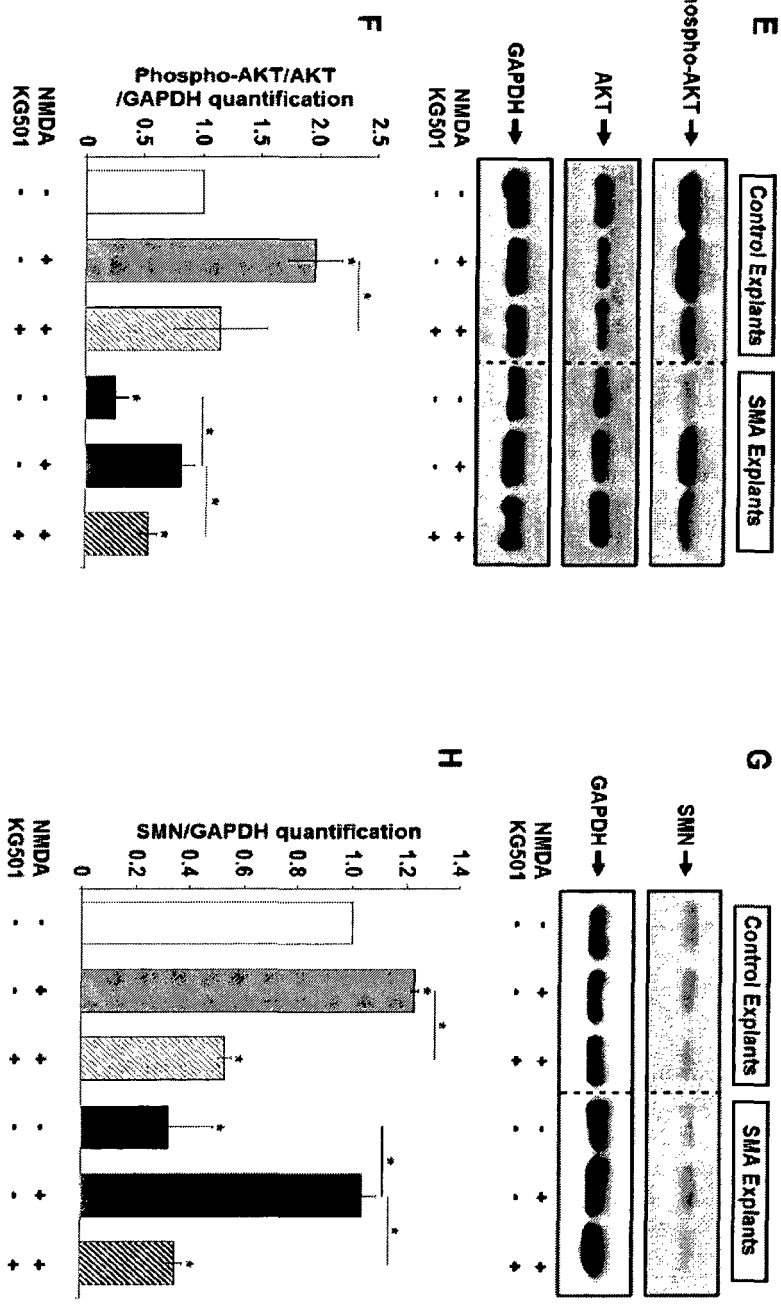

E
phospho-AKT
AKT
GAPDH
Control Explants
SMA Explants
NMDA
KG501
F
Phospho-AKT/AKT
/GAPDH quantification
0
0.5
1.0
1.5
2.0
2.5
G
SMN
GAPDH
H
SMN/GAPDH quantification
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Figure 3

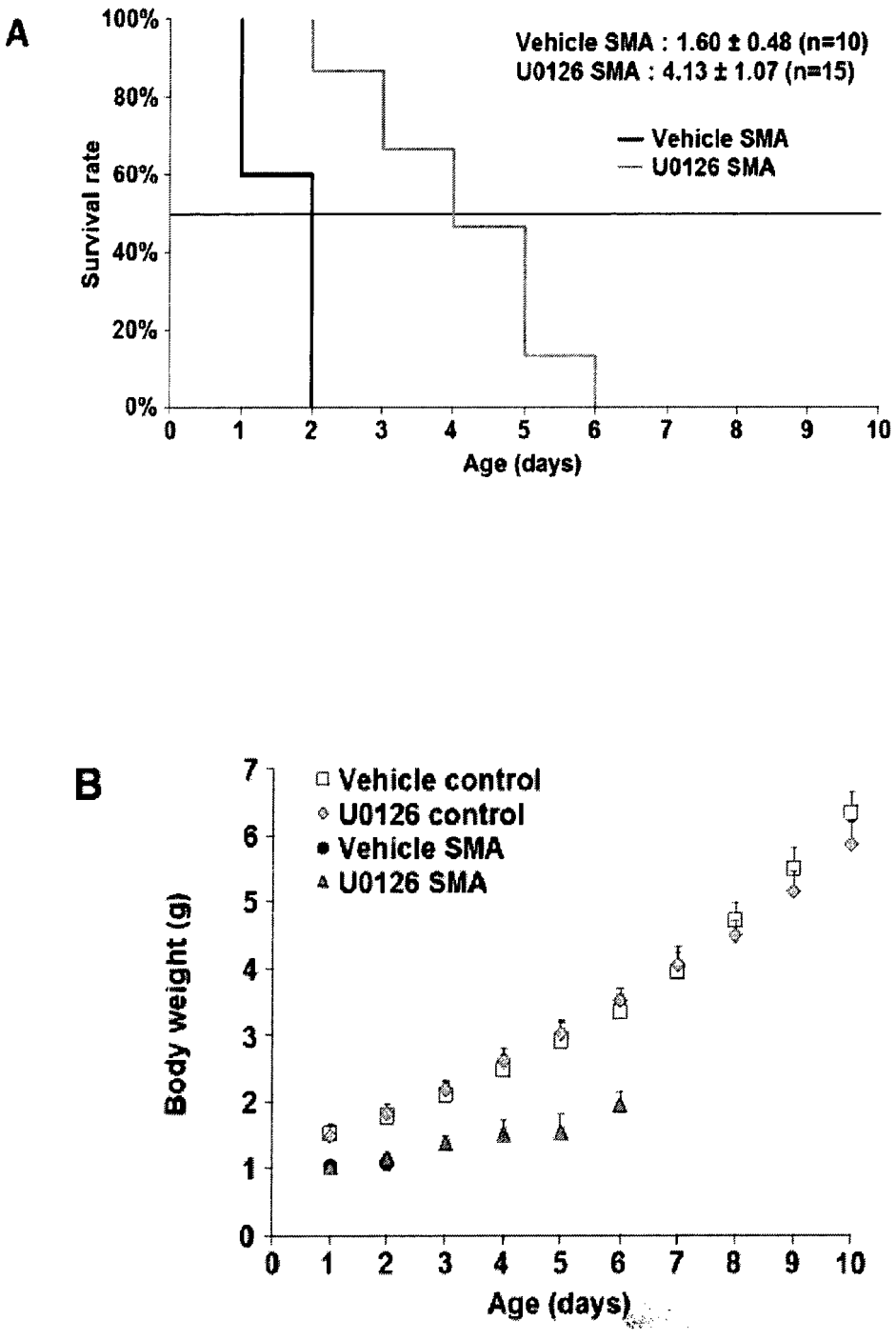

A
100%
80%
60%
40%
20%
0%
Survival rate
0
1
2
3
4
5
6
7
8
9
10
Age (days)
Vehicle SMA : 1.60 ± 0.48 (n=10)
U0126 SMA : 4.13 ± 1.07 (n=15)
Vehicle SMA
U0126 SMA
B
Body weight (g)
Vehicle control
U0126 control
Vehicle SMA
U0126 SMA
Age (days)

FIGURE 4

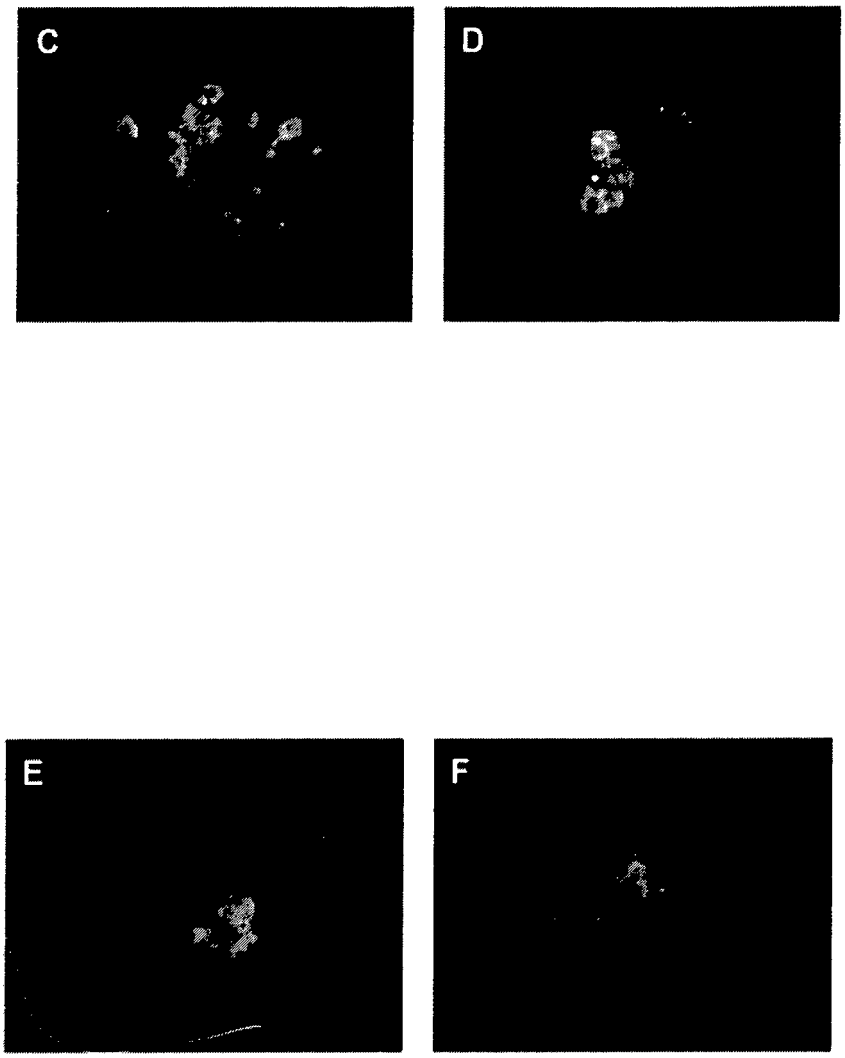
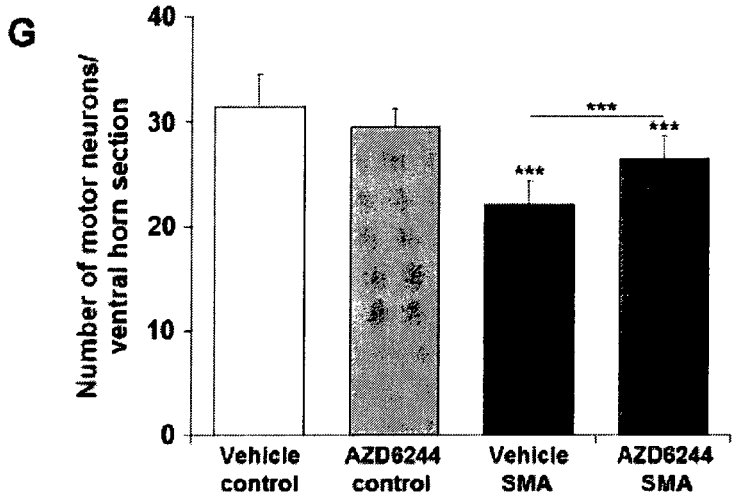
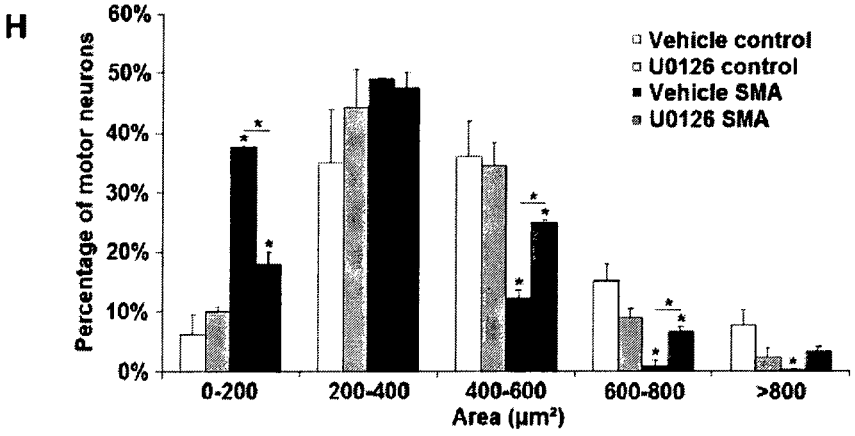


FIGURE 4


G
Number of motor neurons/ ventral horn section
40
30
20
10
0
***
***
***
Vehicle control
AZD6244 control
Vehicle SMA
AZD6244 SMA


H
Percentage of motor neurons
60%
50%
40%
30%
20%
10%
0%
Vehicle control
U0126 control
Vehicle SMA
U0126 SMA
0-200
200-400
400-600
600-800
>800
Area (µm²)

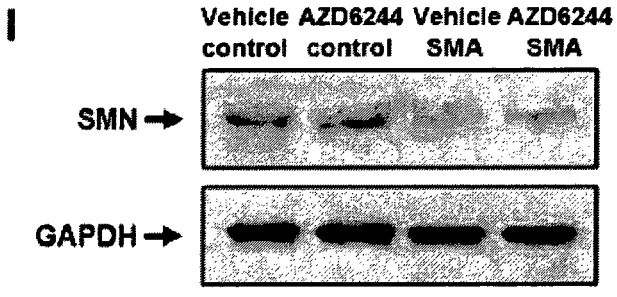
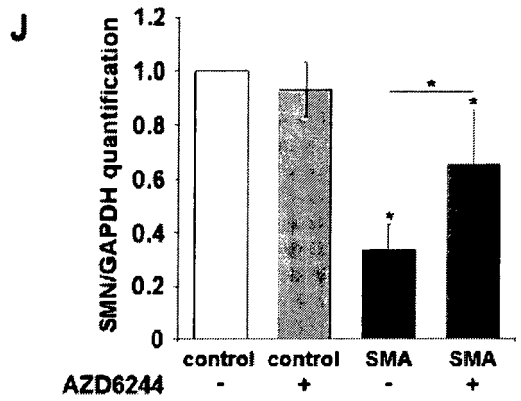
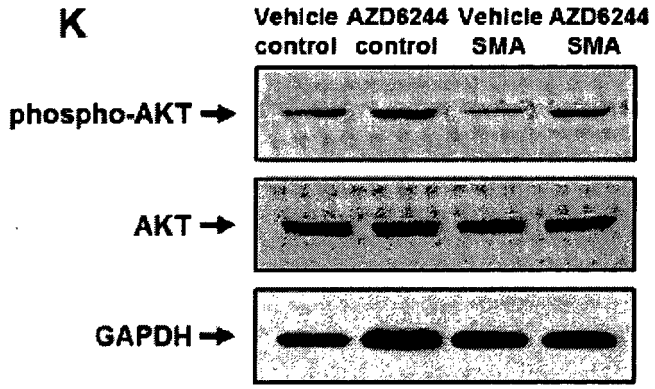

I
Vehicle control
AZD6244 control
Vehicle SMA
AZD6244 SMA
SMN
GAPDH

FIGURE 4


J
SMN/GAPDH quantification
1.2
1.0
0.8
0.6
0.4
0.2
0
control control SMA SMA
AZD6244 - + - +


K
Vehicle AZD6244 Vehicle AZD6244
control control SMA SMA
phospho-AKT
AKT
GAPDH

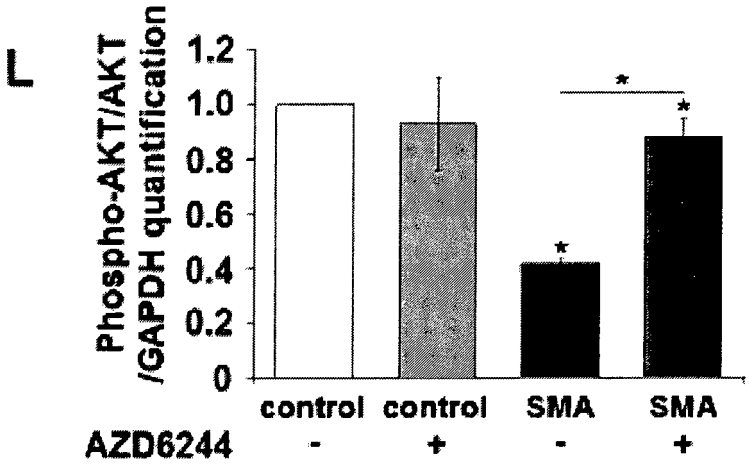
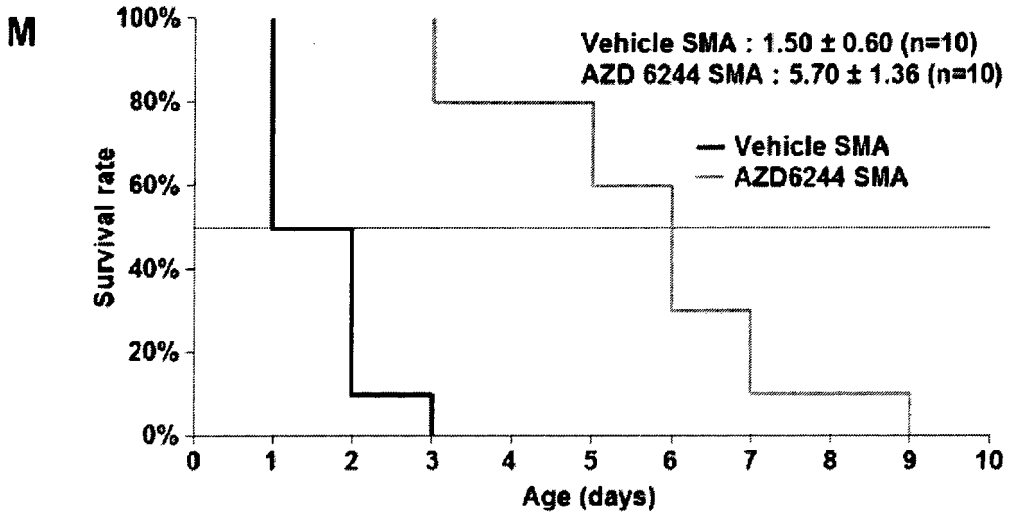

L
Phospho-AKT/AKT
/GAPDH quantification
1.2
1.0
0.8
0.6
0.4
0.2
0
control control SMA SMA
AZD6244 - + - +

FIGURE 4


M
100%
80%
60%
40%
20%
0%
Survival rate
0
1
2
3
4
5
6
7
8
9
10
Age (days)
Vehicle SMA : 1.50 ± 0.60 (n=10)
AZD 6244 SMA : 5.70 ± 1.36 (n=10)
Vehicle SMA
AZD6244 SMA

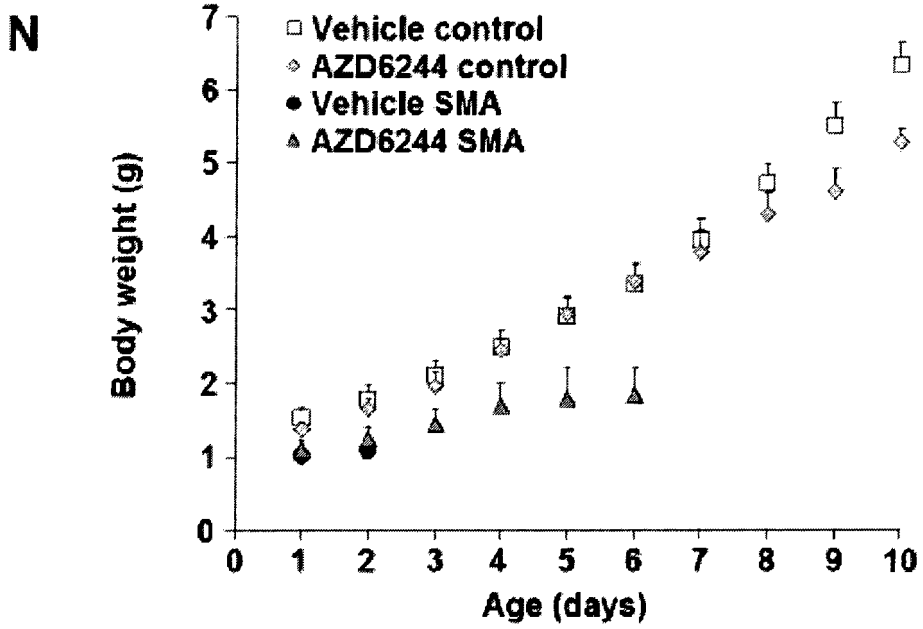

N
Body weight (g)
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
10
Age (days)
Vehicle control
AZD6244 control
Vehicle SMA
AZD6244 SMA

FIGURE 4

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2010148249 A **[0008] [0063]**
- FR 180204 **[0033]**
- US 5525625 A **[0034]**
- WO 9843960 A **[0034]**
- WO 9901426 A **[0034]**
- WO 0041505 A **[0034]**
- WO 0042002 A **[0034]**
- WO 0042003 A **[0034]**
- WO 0041994 A **[0034]**
- WO 0042022 A **[0034]**
- WO 0042029 A **[0034]**
- WO 0068201 A **[0034]**
- WO 0168619 A **[0034]**
- WO 0206213 A **[0034]**
- WO 03077855 A **[0034] [0043]**
- WO 200523251 A **[0034]**
- US 20030060469 A **[0039]**
- US 20040048861 A **[0039]**
- US 20040082631 A **[0039]**
- EP 2275102 A **[0043]**
- WO 03077914 A **[0043]**
- US 6573099 B **[0044]**
- US 6506559 B **[0044]**
- WO 0136646 A **[0044]**
- WO 9932619 A **[0044]**
- WO 0168836 A **[0044]**
- WO 02055693 A **[0044]**
- WO 2010151638 A **[0064]**

Non-patent literature cited in the description

- **ADJEI et al.** *J Clin Oncol,* 2008, vol. 26 (13), 2139-2146 **[0010]**
- **BOARD et al.** *Br J Cancer,* 2009, vol. 101 (10), 1724-30 **[0010]**
- **KOLB et al.** *Pediatr Blood Cancer,* 2010, vol. 55 (4), 668-677 **[0010]**
- **RUNDEN E et al.** *J Neurosci,* 1998, vol. 18 (18), 7296-305 **[0033]**
- **DESILVA, D.R. et al.** *J. Immunol.,* 1998, vol. 160 (4175), 165 **[0033]**
- **DUNCIA, J.V. et al.** *Biorg. Med. Chem. Lett.,* 1998, vol. 8 (2839), 166 **[0033]**
- **FAVATA, M.F. et al.** *J. Biol. Chem.,* 1998, vol. 273 (18623), 167 **[0033]**
- **AHN et al.** *Promega Notes,* 1999, vol. 71, 4 **[0033]**
- **KOHNO ; POUYSSEGUR.** *Prog. Cell. Cyc. Res.,* 2003, vol. 5, 219-224 **[0033] [0035]**
- **ROCHE, WILLIAMS et al.** *Biochemistry,* 30 June 1998, vol. 37 (26), 9579-85 **[0033]**
- **OHORI, M. et al.** *Biochem. Biophys. Res. Comm.,* 2005, vol. 336, 357-363 **[0033]**
- **CHEN, F. et al.** *Bioorg. Med. Chem.,* 2006, vol. 16, 6281-6288 **[0033]**
- **HANCOCK, CN et al.** *J. Med. Chem.,* 2005, vol. 48, 4586-4595 **[0033]**
- **SCHWARZE et al.** *Science,* 1999, vol. 285 (5433), 1569-72 **[0035]**
- **ZHANG N. et al.** *Bioorg Med. Chem. Lett.,* 2000, vol. 10, 2825-2828 **[0036]**
- **WILLIAMS D.H. et al.** *Biochemistry,* 1998, vol. 37, 9579-9585 **[0037]**
- **ZHAO A. et al.** *J. Antibiot.,* 1999, vol. 52, 1086-1094 **[0037]**
- **KNOCKHAERT M. et al.** *Oncogene,* 2002, vol. 21, 6413-6424 **[0038]**
- **TUSCHL, T. et al.** *Genes Dev.,* 15 December 1999, vol. 13 (24), 3191-7 **[0044]**
- **ELBASHIR, S. M. et al.** *Nature,* 24 May 2001, vol. 411 (6836), 494-8 **[0044]**
- **HANNON, GJ.** *Nature,* 11 July 2002, vol. 418 (6894), 244-51 **[0044]**
- **MCMANUS, MT. et al.** *J Immunol,* 2002, vol. 169, 5754-5760 **[0044]**
- **BRUMMELKAMP, TR. et al.** *Science,* 19 April 2002, vol. 296 (5567), 550-3 **[0044]**
- Principles of Retroviral Vector Design. Retroviruses. Plainview, N.Y. Cold Spring Harbor Laboratory Press, 1997 **[0047]**
- **MARTIN E.W.** Remington's Pharmaceutical Science. Mack Publishing Company, 1995 **[0066]**
- **KOLB.** J. Devlin. NY. Marcel Dekker, 1997, 345-360 **[0073]**
- **CRAWFORD, T.O. ; PARDO, C.A.** The neurobiology of childhood spinal muscular atrophy. *Neurobiol. Dis.,* 1996, vol. 3, 97-110 **[0111]**
- **LEFEBVRE, S. et al.** Identification and characterization of a spinal muscular atrophy-determining gene. *Cell,* 1995, vol. 80, 155-165 **[0111]**
- **LORSON, C.L. ; ANDROPHY, E.J.** An exonic enhancer is required for inclusion of an essential exon in the SMA-determining gene SMN. *Hum. Mol. Genet.,* 2000, vol. 9, 259-265 **[0111]**

- **BOARD, R.E. et al.** Detection of BRAF mutations in the tumour and serum of patients enrolled in the AZD6244 (ARRY-142886) advanced melanoma phase II study. *Br. J. Cancer,* 2009, vol. 101, 1724-1730 **[0111]**
- **LORSON, C.L. ; RINDT, H. ; SHABABI, M.** Spinal muscular atrophy: mechanisms and therapeutic strategies. *Hum. Mol. Genet.,* 2010, vol. 19, R111-118 **[0111]**
- **CHANG, J.G. et al.** Treatment of spinal muscular atrophy by sodium butyrate. *Proc. Natl. Acad. Sci. U. S. .A.,* 2001, vol. 98, 9808-9813 **[0111]**
- **AVILA, A.M. et al.** Trichostatin A increases SMN expression and survival in a mouse model of spinal muscular atrophy. *J. Clin. Invest.,* 2007, vol. 117, 659-671 **[0111]**
- **TSAI, L.K. ; TSAI, M.S. ; TING, C.H. ; LI, H.** Multiple therapeutic effects of valproic acid in spinal muscular atrophy model mice. *J. Mol. Med.,* 2008, vol. 86, 1243-1254 **[0111]**
- **THURMOND, J. et al.** Synthesis and biological evaluation of novel 2,4-diaminoquinazoline derivatives as SMN2 promoter activators for the potential treatment of spinal muscular atrophy. *J. Med. Chem.,* 2008, vol. 51, 449-469 **[0111]**
- **BUTCHBACH, M.E. et al.** Effect of diet on the survival and phenotype of a mouse model for spinal muscular atrophy. *Biochem. Biophys. Res. Commun.,* 2010, vol. 391, 835-840 **[0111]**
- **MERCURI, E. et al.** Randomized, double-blind, placebo-controlled trial of phenylbutyrate in spinal muscular atrophy. *Neurology,* 2007, vol. 68, 51-55 **[0111]**
- **SWOBODA, K.J. et al.** Phase II open label study of valproic acid in spinal muscular atrophy. *PLoS One,* 2009, vol. 4, e5268 **[0111]**
- **SWOBODA, K.J. et al.** Project Cure Spinal Muscular Atrophy Investigators Network. SMA CARNI-VAL trial part I: double-blind, randomized, placebo-controlled trial of L-carnitine and valproic acid in spinal muscular atrophy. *PLoS One,* 2010, vol. 5, e12140 **[0111]**
- **BIONDI, O. et al.** In vivo NMDA receptor activation accelerates motor unit maturation, protects spinal motor neurons, and enhances SMN2 gene expression in severe spinal muscular atrophy mice. *J. Neurosci.,* 2010, vol. 30, 11288-11299 **[0111]**
- **MONANI, U.R. et al.** The human centromeric survival motor neuron gene (SMN2) rescues embryonic lethality in Smn(-/-) mice and results in a mouse with spinal muscular atrophy. *Hum. Mol. Genet.,* 2000, vol. 9, 333-339 **[0111]**
- **DUDEK, H. et al.** Regulation of neuronal survival by the serine-threonine protein kinase AKT. *Science,* 1997, vol. 275, 661-665 **[0111]**
- **SOLER, R.M. et al.** Receptors of the glial cell line-derived neurotrophic factor family of neurotrophic factors signal cell survival through the phosphatidylinositol 3-kinase pathway in spinal cord motoneurons. *J. Neurosci.,* 1999, vol. 19, 9160-9169 **[0111]**
- **XIA, Z. ; DICKENS, M. ; RAINGEAUD, J. ; DAVIS, R.J. ; GREENBERG, M.E.** Opposing effects of ERK and JNK-p38 MAP kinases on apoptosis. *Science,* 1995, vol. 270, 1326-1331 **[0111]**
- **WHITMARSH, A.J. ; SHORE, P. ; SHARROCKS, A.D. ; DAVIS, RJ.** Integration of MAP kinase signal transduction pathways at the serum response element. *Science,* 1995, vol. 269, 403-407 **[0111]**
- **YANG, S.H. ; SHORE, P. ; WILLINGHAM, N. ; LAKEY, J.H. ; SHARROCKS, A.D.** The mechanism of phosphorylation-inducible activation of the ETS-domain transcription factor Elk-1. *EMBO J.,* 1999, vol. 18, 5666-5674 **[0111]**
- **ZHANG, H.M.** Mitogen-induced recruitment of ERK and MSK to SRE promoter complexes by ternary complex factor Elk-1. *Nucleic Acids Res.,* 2008, vol. 36, 2594-2607 **[0111]**
- **MAJUMDER, S. et al.** Identification of a novel cyclic AMP-response element (CRE-II) and the role of CREB-1 in the cAMP-induced expression of the survival motor neuron (SMN) gene. *J. Biol. Chem.,* 2004, vol. 279, 14803-14811 **[0111]**
- **DEMIR, O. et al.** ETS-domain transcription factor Elk-1 mediates neuronal survival: SMN as a potential target. *Biochim. Biophys. Acta,* 2011, vol. 1812, 652-662 **[0111]**
- **KOLB, E.A et al.** Initial testing (stage 1) of AZD6244 (ARRY-142886) by the Pediatric Preclinical Testing Program. *Pediatr. Blood Cancer,* 2010, vol. 55, 668-677 **[0111]**
- **KOBAYASHI, T. ; ASKANAS, V. ; ENGEL, W.K.** Human muscle cultured in monolayer and cocultured with fetal rat spinal cord: importance of dorsal root ganglia for achieving successful functional innervation. *J. Neurosci.,* 1987, vol. 7, 3131-3141 **[0111]**
- **BIGOT, A. et al.** Large CTG repeats trigger p16-dependent premature senescence in myotonic dystrophy type 1 muscle precursor cells. *Am. J. Pathol.,* 2009, vol. 174, 1435-1442 **[0111]**
- **TOWBIN, H. ; SCHOENENBERGER, C. ; BALL, R. ; BRAUN, D.G. ; ROSENFELDER, G.** Glycosphingolipid-blotting: an immunological detection procedure after separation by thin layer chromatography. *J. Immunol. Methods.,* 1984, vol. 72, 471-479 **[0111]**